USING OSCILLATING FANS TO IMPROVE COMFORT

by

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ABSTRACT

Using oscillating fans to improve comfort.

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Eight subjects sat in an experimental chamber and performed a pegboard task three different times at three different temperatures (25.6, 27.8, and 30 C). In each temperature there were seven conditions (1- Performing the task in still air, no fan in use: 2,3,4- Performing the task while the fan was in a fixed position at three air velocities: 5,6,7- Performing the task while the fan was oscillating at three air velocities). Air velocities were at .4, .8, and 1.2 m/s.

Each subject was exposed to each temperature and fan condition for 20 minutes. Two types of ballots measured the subjects thermal sensation.

Results indicated that temperatures and fan conditions were significantly different. The interactions between fan conditions and temperatures were not significant.

Subjects felt cooler with higher air velocities independent of the fan condition or temperature.

At lower temperatures the oscillating fan was perferred over the fixed fan, while at higher temperatures both fan conditions had the same effect. For every increase in air velocity by 1 m/s the temperature can be increased by 2.2 C for the oscillating fan and by 5.5 C for the fixed fan.

INTRODUCTION

Thermal comfort is defined by the American Society for Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) standard 55-74 as "The condition of the mind that expresses satisfaction with the thermal environment." Thermal environment means the air temperature, mean radiant temperature, air velocity, and humidity: a combination of these will create thermal comfort. Thermal comfort is not an exact concept and does not occur at a certain temperature. The condition of the mind is related to the condition of the body (heart rate, mean skin temperature, sweat rate, etc). Some of the non-thermal factors that do not affect the condition of the mind are:

The season of the year- Konz (1979) said that comfort is not affected by the season of the year.

Age- Cena and Clark (1981) said that, although the metabolic rate decreases with age, this is fortuitously compensated by a decrease in insensible evaporation.

Sex- Cena and Clark (1981) said that women are more sensitive to temperature change away from the comfort temperatures. However, Cena and Clark mention that, in practice, there is no need to differentiate between sexes for comfort temperatures.

Colors- Do not affect thermal sensation according to Cena and Clark (1981).

Time of day- Time of the day has no effect on thermal comfort conditions according to Konz (1979).

There is a relationship between the physiological response (condition of the body) and the psychological response (condition of the mind). This study will investigate the psychological response.

Psychological responses Rohles and Nevins (1971) had 1600 subjects exposed to 160 combinations of temperature and humidity where results showed a very wide variation in subject's votes. The range of subject's voting comfortable was between 62 F and 98 F (16.7 C and 36.7 C) after an exposure of three hours. This study shows the variation and differences among people.

Rohles et al. (1967) had subjects exposed to six temperatures between 95 and 120 F (35 and 48.9 C) and to different relative humidities. The rectal temperature was measured. Results showed that when the effective temperature was below 91.3 F (32.9 C) there was no increase in the rectal temperature above 2 F (1.1 C) for all subjects. However all subjects had the 2 F (1.1 C) increase when the effective temperature was 97 F (36.1 C) and above. The above study was mentioned by Rohles (1971); he sub-divided the difference between people into a variation between-subjects and a variation within-subjects. At higher temperatures both variations will be reduced and subjects will feel the same. Rohles goes on to mention that, in contrast, when temperatures are between 68 F and 75 F (20 and 23.9 C) with relative humidity at 50% and with an air velocity below 50 ft/min (.25 m/s), both variations (between and within subjects) will increase and measuring that variability will become more complex.

Rohles (1980), in reviewing studies which address the psychology of thermal comfort, mentioned that at 65 F (19.3 C) secretaries that were told that a radiant heater was operating voted warmer than those that were not told. In another study reviewed by Rohles, people that were told that the room temperature was 74 F (23.3 C), while the actual temperature was 72, 70, and 68 F (22.2, 21.1, and 20 C), felt as comfortable as when the room temperature was 74 F. From the above can be seen the importance of the psychological responses (condition of the mind).

Humidity Rohles (1971) had 1600 college age students (males and females) exposed to temperatures ranging between 60 and 98 F (15.6 and 36.7 C) and to relative humidities between 15 and 80%. "Comfortable" votes were given over a temperature range between 62 and 98 F (16.7 and 36.7 C). Male subjects took a longer time to adapt to the thermal environment than the female subjects did. For male subjects the temperature is about seven times more important than humidity when determining the thermal sensation, but for females it is about nine times more important. The matter of how humidity affects the preferred temperature was discussed by Cena and Clark (1981). Fanger's comfort equation predicts that a change in relative humidity from 20% to 75% will reduce the preferred temperature by only .5 C (1 F). Ingram and Mount (1975) said that the change from dry air to saturated air is compensated for by a fall in the comfort temperature of 1.5 to 3 C (3 to 6 F). The strongest effect of humidity will be at higher temperatures and when these temperatures are higher than the comfort temperatures.

Mean radiant temperature and clothing Konz (1979) mentions that, for each 1 C (2 F) deviation of the mean radiant temperature (MRT) from the Dry Bulb Temperature (DBT), the DBT changes 1 C (2 F) in the oppsite direction. ASHRAE standard 55-74 section 5.1.4 defines the operative temperature as the mean of the air temperature and the mean radiant temperature. So, when the MRT differs from the air temperature, one of the temperatures should be adjusted to keep the operative temperature within the comfort zone.

Nevins (1975) says that the DBT decreases .6 C for every .1 clo increase. Konz (1979) cited Nevins and Gorton that when the total metabolism is less than 225 W the DBT decreases .6 C for every .1 clo increase starting from .6 clo, and when the metabolism is over 225 W the DBT decreases by 1.2 C for every .1 clo.

Air velocity By controlling the ambient air temperature, the mean radiant temperature and the humidity, the remaining factor from which thermal comfort can be created is the air velocity. Fanger (1979) cited Bedford and Warner that "the air movement should be variable rather than uniform and monotonous, for the body is stimulated by ceaseless change in the environment."

Rohles (1965) had two monkeys exposed to three different air velocities of 5, 10, and 20 mph (2.2, 4.5, and 8.9 m/s) and to three different temperatures of 50, 60, and 70 F (10, 15.6, and 21.1 C). The monkeys chose to avoid the wind most of the time. There was a reduction of avoidance at the 60 F temperature. The wind velocities of 10 and 20 mph were avoided most of the time. Later on Rohles (1965), in another study, made a hypothesis that when the air temperature is low, a wind at a certain velocity will be unpleasant but when the temperatures are slightly above the comfort zone (between 80 and 90 F) the same wind velocity will be pleasant. When the temperature is high (over 90 F), the wind becomes unpleasant again.

Berdan et al. (1970) had eight subjects exposed to temperatures between 15 and 35 C (59 and 95 F), and to air velocities up to 4 m/s. Physiological reactions were recorded. In moderate work, favorable results were obtained with air temperatures between 20 and 27 C at air velocities up to 3 m/s. Results also indicated that the sweat rate and skin temperature decreased as the air velocity increased for all experimental temperatures.

Olesen et al. (1972) had a subject examined at sixteen conditions of air temperature, mean radiant temperature, clothing, activity and air velocity. Air velocity was created by a rectangular nozzle facing the subject. There was no difficulty in creating thermal comfort at .8 m/s. The evaporative weight loss increased when air velocity increased. The mean skin temperature and evaporative loss were independent from the combination of air velocity, mean radiant temperature, air temperature and clothing at a given activity level when the subject was thermally comfortable. The subject's vote was not influenced by the mean skin temperature or evaporative loss. But the mean skin temperature and evaporative loss did have an influence when the air temperature was higher than the mean radiant temperature; the study showed that the subject preferred a skin temperature approximatly .8 C lower than when both temperatures were equal.

Fanger et al. (1974) had subjects seated and exposed to a velocity of .8 m/s from five directions (front, side, behind, below, and above) with the air temperature chosen individually by each subject. There was no difficulty in creating thermal comfort independent of the direction of the air flow. The study also mentioned that besides the mean velocity, the turbulence (fluctuation) of air flow may have an influence in man's heat balance and his comfort.

Fanger (1970) developed a mathematical model which predicts thermal comfort at different environmental conditions. The comfort equation was stated as:
(Internal heat production in the human body) - (Heat loss due to water vapour diffusion through the skin) - (Heat loss due to the evaporation of sweat from the surface of the skin) - (Latent respiration heat loss) - (Dry respiration heat loss) - (Dry respiration heat loss)=
(Heat loss by radiation from the outer surface of the clothed body + The heat loss by convection from the outer surface of the clothed body).
The right side of the equation equals the heat production while the left side equals the heat dissipation. The mathematical terms of the model is stated as:

$$\frac{M}{A_{Du}}(1-n) - .35\left\{43 - .061\frac{M}{A_{Du}}(1-n) - pa\right\} -$$

$$.42\left\{\frac{M}{A_{Du}}(1-n) - 50\right\} - .0023\frac{M}{A_{Du}}(44 - pa) -$$

$$.0014\frac{M}{A_{Du}}(34 - t_a) = 3.4 \cdot 10^{-8} f_{cl}\left\{(t_{cl} + 273)^4 -\right.$$

$$\left.(t_{mrt} + 273)^4\right\} + f_{cl}\, h_c\,(t_{cl} - t_a)$$

Where:

M = Metabolic rate, Kcal/hr

A_{Du} = Body surface area of the human body (DuBois area), m^2

t_{cl} = Mean temperature of outer surface of clothed body, C

t_{mrt} = Mean radiant temperature, C

pa = Partial pressure of water vapor in ambient air, mmHg

n = External mechanical efficiency of the body, where n = (external mechanical power)/(metabolic value).

t_a = Air temperature, C

f_{cl} = Ratio of surface area of clothed body to surface area of the nude body.

h_c = Convective heat transfer coefficient, where $h_c = 10.4\,(V)^{.5}$ (Kcal/hr m^2 C)

V = Air velocity, m/s

This equation was employed by Rohles et al. (1974) in a study where they had 90 subjects exposed to three air velocities of 40, 80, and 160 ft/min (.2, .4, and .8 m/s) and to three air temperatures. The three air velocities were created by blowers mounted outside the experimental chamber. The preferred temperature was not identical to those obtained from Fanger's equation. This lack of agreement was explained as due to the low air velocities that are difficult to measure. Results from this study indicated that thermal sensation may be linearly correlated with the new effective temperature and air movement. The weighted mean skin temperature was influenced by temperature and air velocity.

Fanger (1975), in discussing convective spot cooling, said that comfort can be created by controlling one's convective heat loss. This could be done by creating and controlling the air flow. That is, thermal comfort can be created by increasing the air velocity at an individual work place in warm buildings. Figure 1 shows a comfort diagram based on Fanger's comfort equation. With a combination of air velocity and air temperature at a certain activity level, comfort can be created. Figure 1 also shows that if the air temperature is higher than 29 - 30 C (84.2 - 86 F) comfort can not be achieved through higher air velocities. Furthermore, the matter of using the air velocity at each individual place is favorable from the point that people are different. Each can control the system according to their own requirements

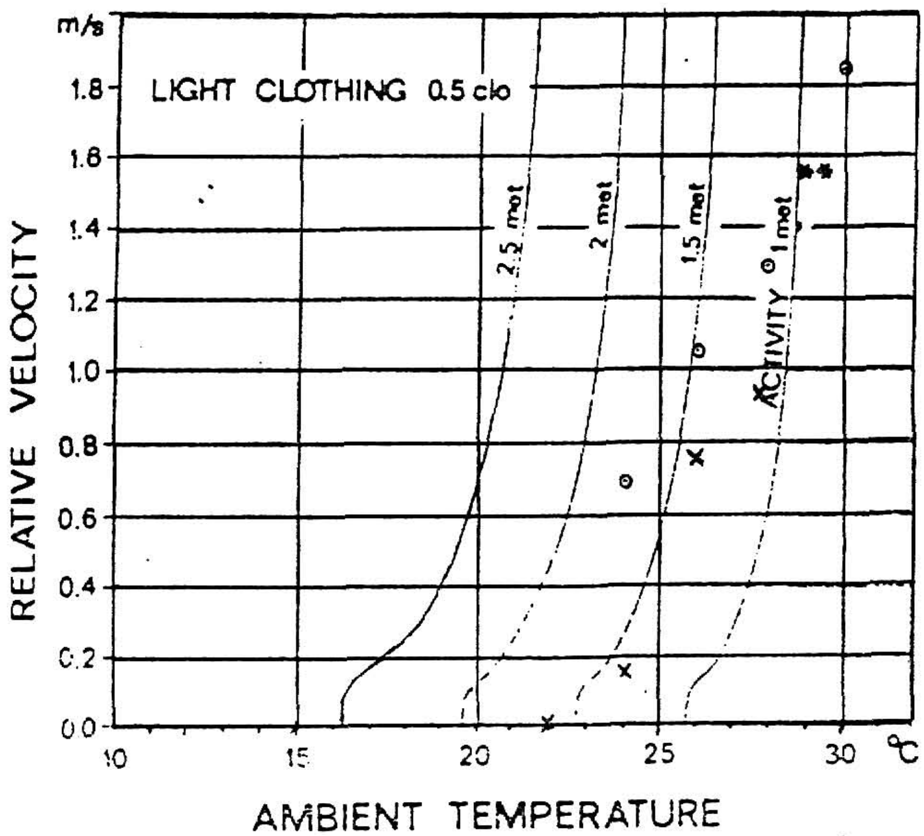

Figure 1 Comfort diagram based on Fanger's equation, where it shows the required velocity at a given temperature and activity level.

⊙ McIntyre's experiment, males

× McIntyre's experiment, females

** 1 met = 58 W/m^2 .

and needs.

McIntyre (1980) investigated the preferred air velocity for comfort. Eleven subjects were exposed to temperatures ranging from 22 to 30 C (72 to 86 F), and to air velocities chosen by each subject by regulating a ceiling fan. The use of a ceiling fan reduced discomfort at warm temperatures. Air velocities chosen by subjects at different temperatures are plotted in Figure 1. Subjects chose velocities up to 2 m/s at 30 C (86 F). This confirms Fanger's comfort diagram. Subjects also chose air velocities that increased with the increase of air temperature.

Nevins (1975) said that for each .1 m/s increase in velocity up to .6 m/s the DBT should be increased by .3 C. For every .1 m/s increase between .6 and 1.0 m/s, the DBT should be increased by .15 C.

From all above, fans do make a difference. In warm conditions air movement may be used to reduce discomfort. Although fans can not reduce humidity, they provide a cheap and effective method of relief from heat. Air velocity can be used to create thermal comfort within reasonable ranges of air temperature, mean radiant temperature and humidity.

Oscillating fans Air flow in previous studies was created by the use of blowers, nozzles, and ceiling fans. This study will investigate the use of oscillating fans and thermal comfort created by their use. Consumer Reports (1979) mentions that "oscillating fans have their most cooling effect when they move from side to side (oscillate). Oscillating fans provide a convenient method for creating air movement. No installation is needed as any flat surface will do. Oscillating fans can be set up to run without oscillation, simply by adjusting a control knob. An oscillating fan also provides a wide range of air distribution depending on the distance between people and the fan, as can be seen in Figure 2. This investigation of oscillating fans will be done by exposing subjects to different temperatures and to different air velocities to see how effective oscillating fans can be, by studying subject's response (votes) from these conditions.

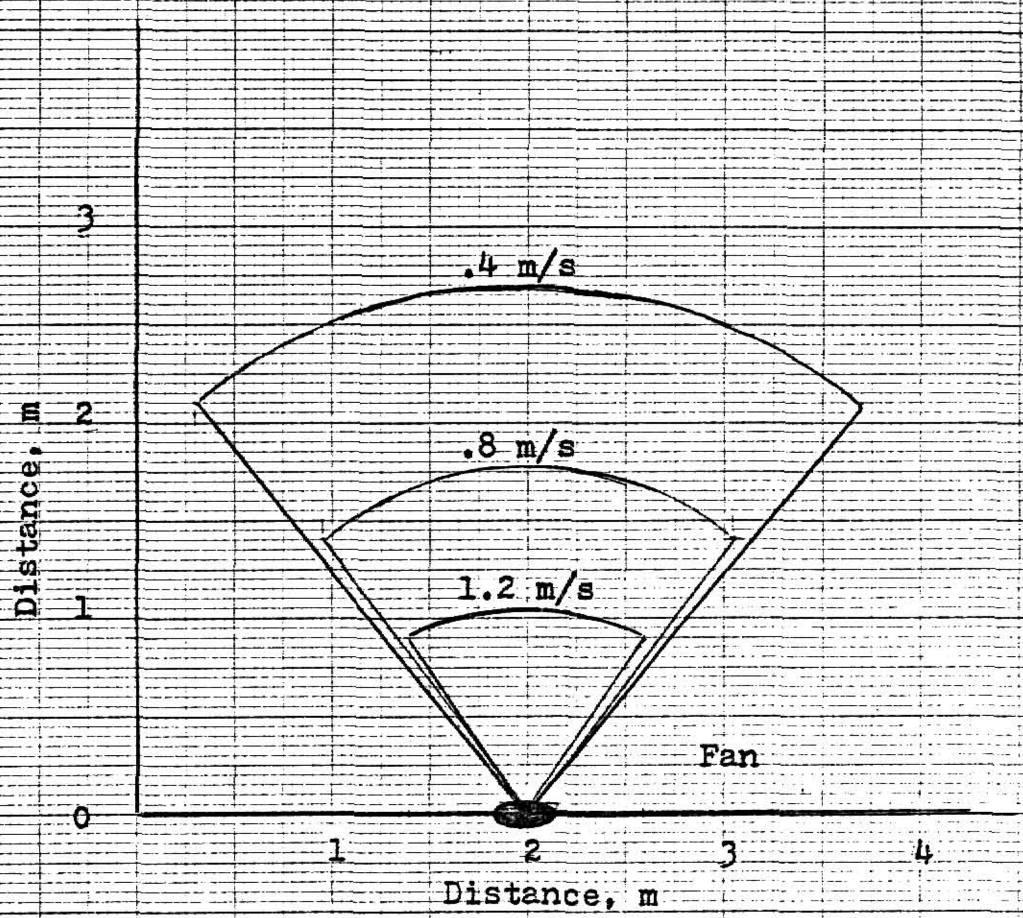

Figure 2 Fan air flow contours show an increase in the area affected by the air flow with the increase in distance.

METHOD

Task

Subjects wearing the KSU standard uniform (see below) entered the IER chamber on three different days and performed a pegboard task. See Figure 3. They picked up doubles from the bin one at a time using their preferred hand and placed them in a pegboard. Subjects then disassembled the board and repeated the process.

Subjects

Eight male college-age students participated in the experiment. Subjects were paid $45 for their participation.

Experimental Design

The experiment was conducted in the Institute of Environmental Research (IER) chamber.

Before entering the chamber, each subject changed into the clothing required for the experiment. This consisted of a shirt (long sleeves, cotton twill), trousers (cotton), socks (cotton), jockey shorts, and shoes. This represents the KSU standard uniform which has a value of .6 clo. Then subjects entered the chamber. This was done three different times in three different days. Once in the chamber the instructions were read to the subjects (Appendix B). Then they completed the subject data form (Appendix C). The subjects were shown the two types of ballots that were distributed among them every ten minutes of

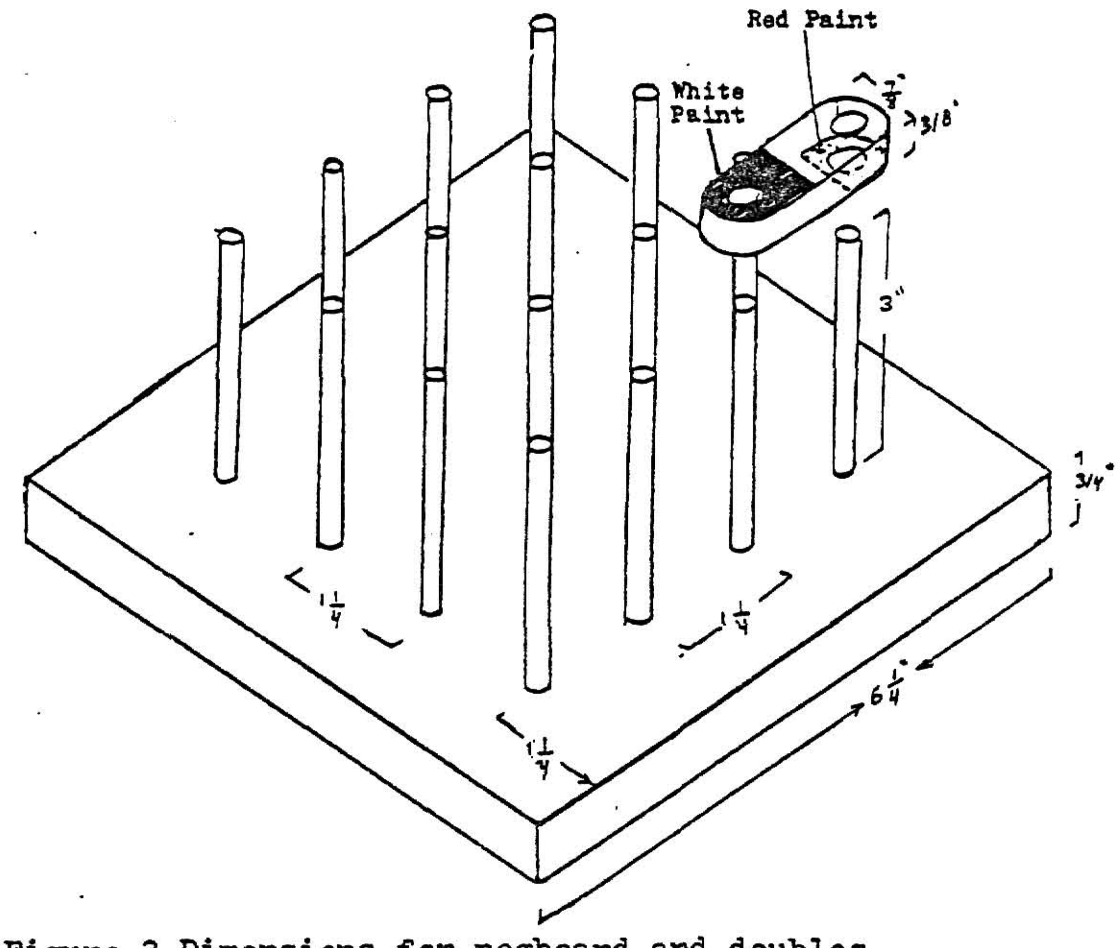

Figure 3 Dimensions for pegboard and doubles.

the experiment (Appendices D and E). Afetr the subjects learned how to mark the ballots, the experiment began.

Subjects were seated at the table and performed the pegboard task in seven conditions:

1- Performing the task in still air (air velocity less than .2 m/s).

2,3,4- Performing the task while the fan was in a fixed position at three air velocities (.4, .8, and 1.2 m/s)

5,6,7- Performing the task while the fan was oscillating at three air velocities (.4, .8, and 1.2 m/s).

This was done on three different days and at three different temperatures of 25.6, 27.8, and 30 C (78, 82, and 86 F). Humidity was fixed at 50%. The mean radiant temperature was equal to the air temperature. Subjects were run two at a time, with each subject facing the fan, Figures 4 and 5.

Every ten minutes of the experiment, and for a total time of 160 minutes, ballots were distributed for each subject.

The first condition, no fan in use (NF), was repli cated and was fixed for the first two periods and the last two periods. The second through the seventh condition, fan in fixed position (FF) and fan oscillating (FO), also

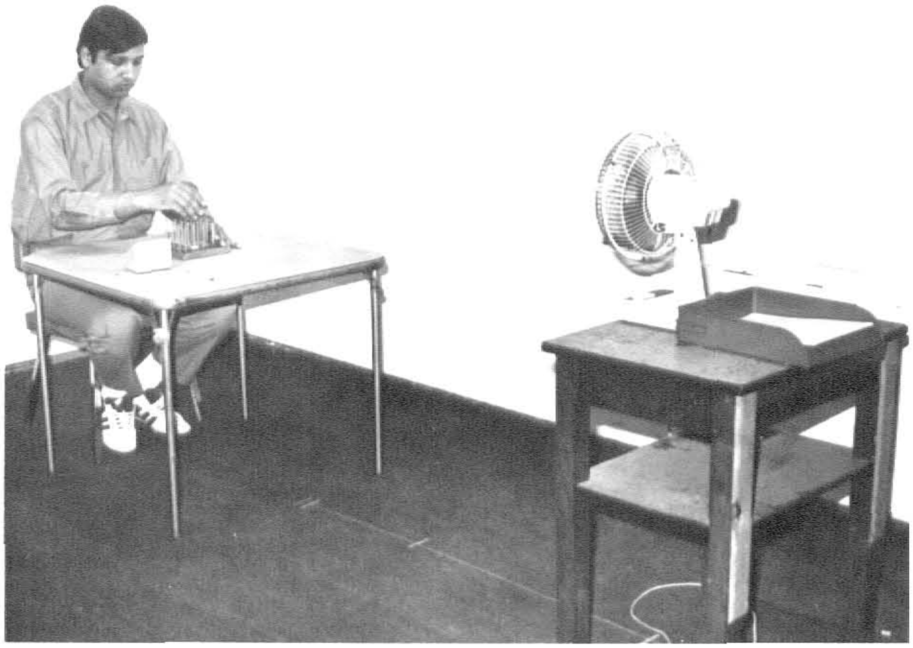

Figure 4 Subject performing the pegboard task while the fan is in a fixed position.

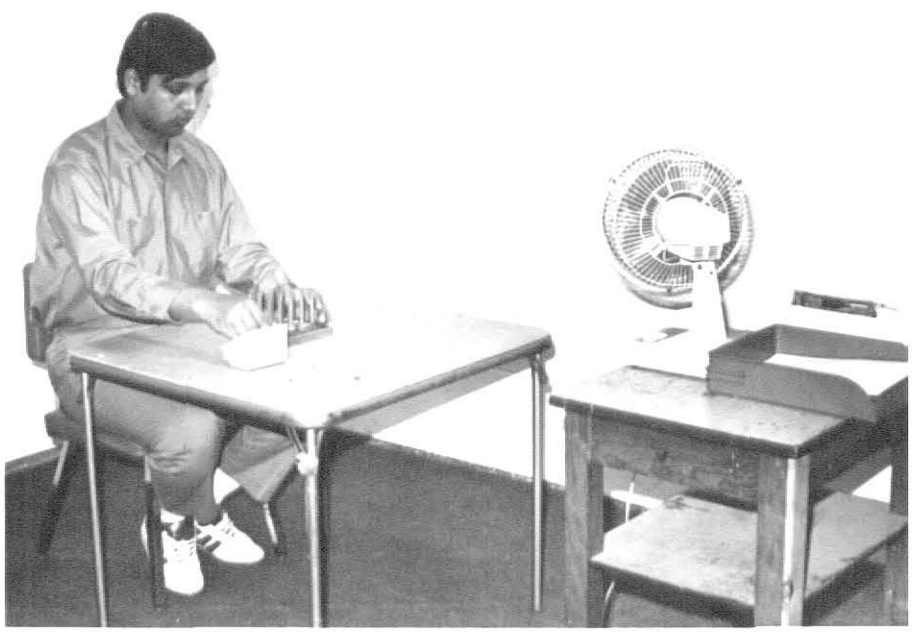

Figure 5 Subject performing the pegboard task while the fan is oscillating.

were replicated and randomly distributed among the remaining periods. See Table 1. Temperatures were randomly distributed. See Table 2.

Measurements and Instrumentation

Two electric nine inch oscillating fans (Model LA-9, Tatung Company of America Inc.) were used to create the air flow inside the chamber while two subjects were working at the same time. See Figure 6. Air velocity was measured using a velometer (Type 6006-P, ALNOR).

Measuring air velocity was done by placing a fan in front of the subject's face, and by placing the ALNOR velometer at a point that represents the center of the subject's face. See Figure 7. The fan was moved forward and backward to determine the air velocity for both conditions (fan fixed and fan oscillating). The air flow created by the fan in both conditions was not in a steady mode; this caused the velometer to fluctuate. An anometer (Model 60, Anemotherm) was used to check that same air flow. It also gave a fluctuating reading. Although the fluctuation of the anometer was slower than that of the velometer, it was decided to use the velometer because more accurate readings could be obtained from it as the distance between the figures on the dial are greater than that of the anometer.

Three air velocities were needed (.4, .8, and 1.6 m/s).

TABLE 1

Sequence of the experiment at a temperature.

Subject																
1	NF	NF	FO_3	FO_3	FO_2	FO_2	FF_1	FF_1	FF_3	FF_3	FF_2	FF_2	FO_1	FO_1	NF	NF
2	NF	NF	FO_2	FO_2	FF_1	FF_1	FO_1	FO_1	FF_2	FF_2	FO_3	FO_3	FF_3	FF_3	NF	NF
3	NF	NF	FF_3	FF_3	FF_2	FF_2	FO_3	FO_3	FO_1	FO_1	FF_1	FF_1	FO_2	FO_2	NF	NF
4	NF	NF	FO_1	FO_1	FF_2	FF_2	FF_3	FF_3	FF_1	FF_1	FO_3	FO_3	FO_2	FO_2	NF	NF
5	NF	NF	FO_2	FO_2	FF_2	FF_2	FO_3	FO_3	FF_1	FF_1	FF_3	FF_3	FO_1	FO_1	NF	NF
6	NF	NF	FO_3	FO_3	FF_2	FF_2	FO_2	FO_2	FF_1	FF_1	FF_3	FF_3	FO_1	FO_1	NF	NF
7	NF	NF	FO_1	FO_1	FF_2	FF_2	FO_3	FO_3	FO_2	FO_2	FF_3	FF_3	FF_1	FF_1	NF	NF
8	NF	NF	FO_1	FO_1	FF_1	FF_1	FF_3	FF_3	FO_3	FO_3	FF_2	FF_2	FO_2	FO_2	NF	NF

NF - No fan in use

FF_1 - Fan fixed at velocity .4 m/s

FF_2 - Fan fixed at velocity .8 m/s

FF_3 - Fan fixed at velocity 1.2 m/s

FO_1 - Fan oscillating at velocity .4 m/s

FO_2 - Fan oscillating at velocity .8 m/s

FO_3 - Fan oscillating at velocity 1.2 m/s

TABLE 2

Sequence of the experiment by temperature.

Subjects	Temperature		
1 and 2	82	86	78
3 and 4	86	82	78
5 and 6	86	78	82
7 and 8	78	82	86

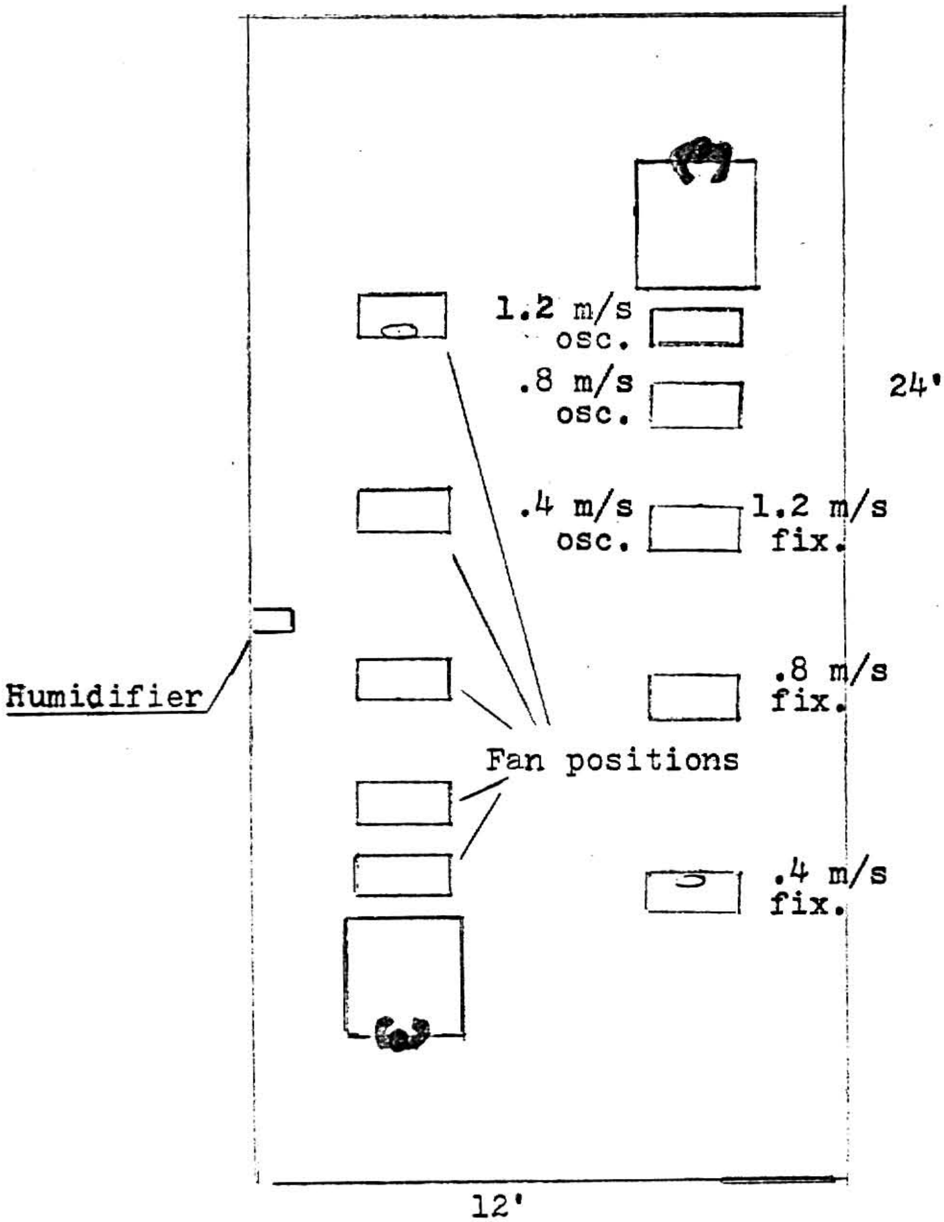

Figure 6 Experimental chamber

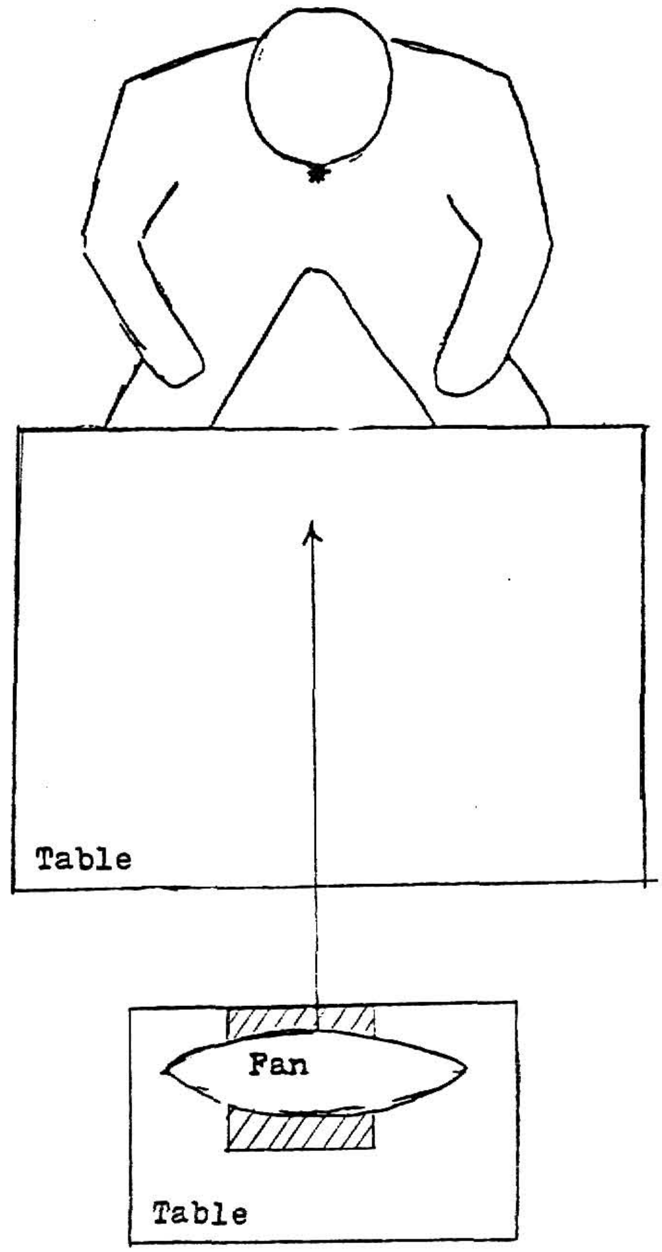

Figure 7 Measuring the air velocity while the fan is in fixed position. (*) Point where air velocity was measured.

In order to obtain an air velocity of 1.6 m/s when the fan was oscillating, the subject needed to be approximately .3 meters (one foot) away from the center of the fan. When the fan oscillated, that left a distance of .2 meters (nine inches) between the subject's face and the edge of the fan; see Figure 8. It was decided that this was an uncomfortable position and a velocity of 1.2 m/s was chosen instead.

1- Air velocity when the fan is at a fixed position:

Fifty air velocity readings were taken (one every five seconds) for every half foot. Means and standard deviations were calculated to determine the required velocities; see Table 3. Air velocity means were plotted and a curve was fitted between the data points using a SAS (Statistical Analysis System) program; see Figure 9. The best equation is:

$$AV = 12.323 + 6.174\,(D) - .322\,(D)^2 - 15.647\,(D)^{.5}$$

$$R^2 = .989$$

where

AV = Air velocity, m/s

D = Distance, meters

For a velocity of .4 m/s the fan should be approximately 4.5 meters away from the subject. For a velocity of .8 m/s the fan should be approximately 3.2 meters away from the

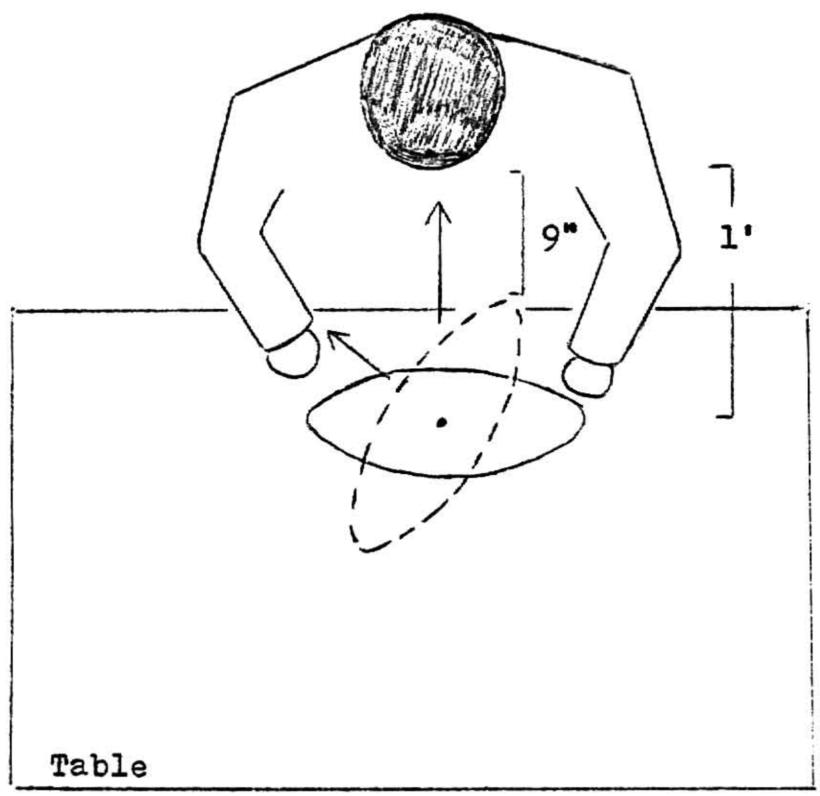

Figure 8 Position of the oscillating fan at a velocity of 1.6 m/s.

TABLE 3

Mean air velocity at different distances for Tatung fan in a fixed position.

Distance (meters)	Mean air velocity (m/s)	Standard Deviation
1.83*	1.37	
1.98*	1.33	
2.13	1.13	.165
2.29	1.09	.159
2.44	.98	.188
2.59	.96	.161
2.74	.98	.179
2.90	.88	.164
3.05	.83	.122
3.20	.83	.121
3.35	.77	.137
3.51	.73	.152
3.66	.64	.144
3.81	.59	.163
3.96	.61	.138
4.11	.57	.119
4.27	.46	.137
4.42	.43	.108
4.57	.35	.106
4.72	.33	.116

*) Some of the readings are not accurate because of the limited range of the velometer.

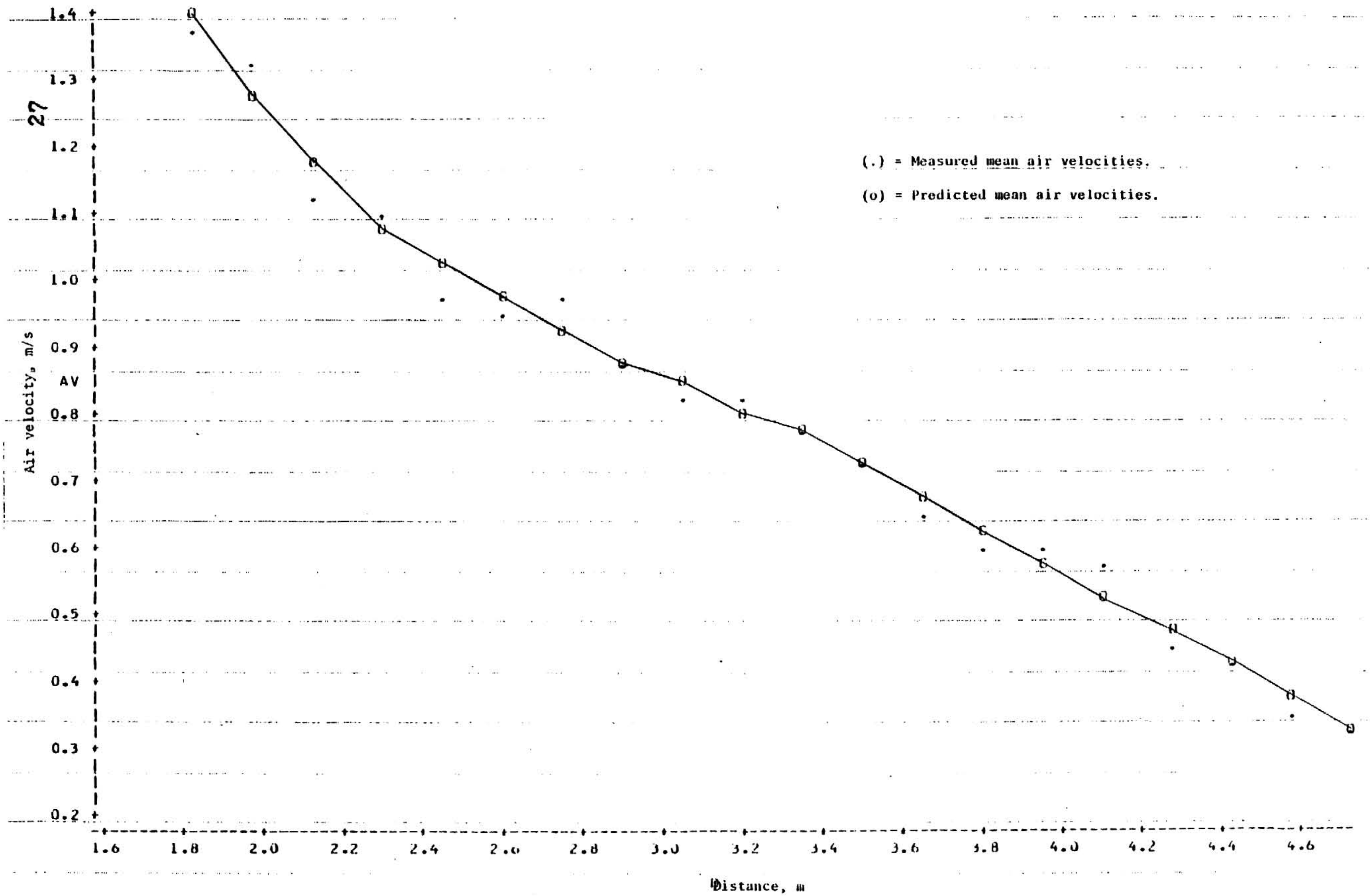

Figure 9 Mean air velocity of the fixed fan at different distances.

subject. For a velocity of 1.2 m/s the fan should be approximately 2.1 meters away from the subject. Readings for the velocity of .8 m/s are plotted in Figure 10. Note the great variability over time for a "steady state" fan. These fluctuations are due to reflections from the wall and blade variation and probably are typical of such fans in actual operating conditions. For all velocities the side of the fan was approximately .8 meters from the wall.

2- Air velocity when the fan is oscillating:

The fan oscillated through an angle of 80 degrees; see Figure 11. Fifty maximum air velocity readings were taken. Each reading was determined both when the fan oscillated from left to right and from right to left. This means that when a fan completed one cycle, two readings were taken (one every five seconds). Means and standard deviations were calculated; see Table 4. Maximum air velocity means were plotted and a curve was fitted between the data points using a SAS program. See Figure 12. The best equation is:

$$AV = .961 + .116\,(D) - 1.021\,(\ln(D))$$

$$R^2 = .990$$

where

AV = Air velocity, m/s

D = Distance, meters

For a maximum velocity of .4 m/s the fan should be approx-

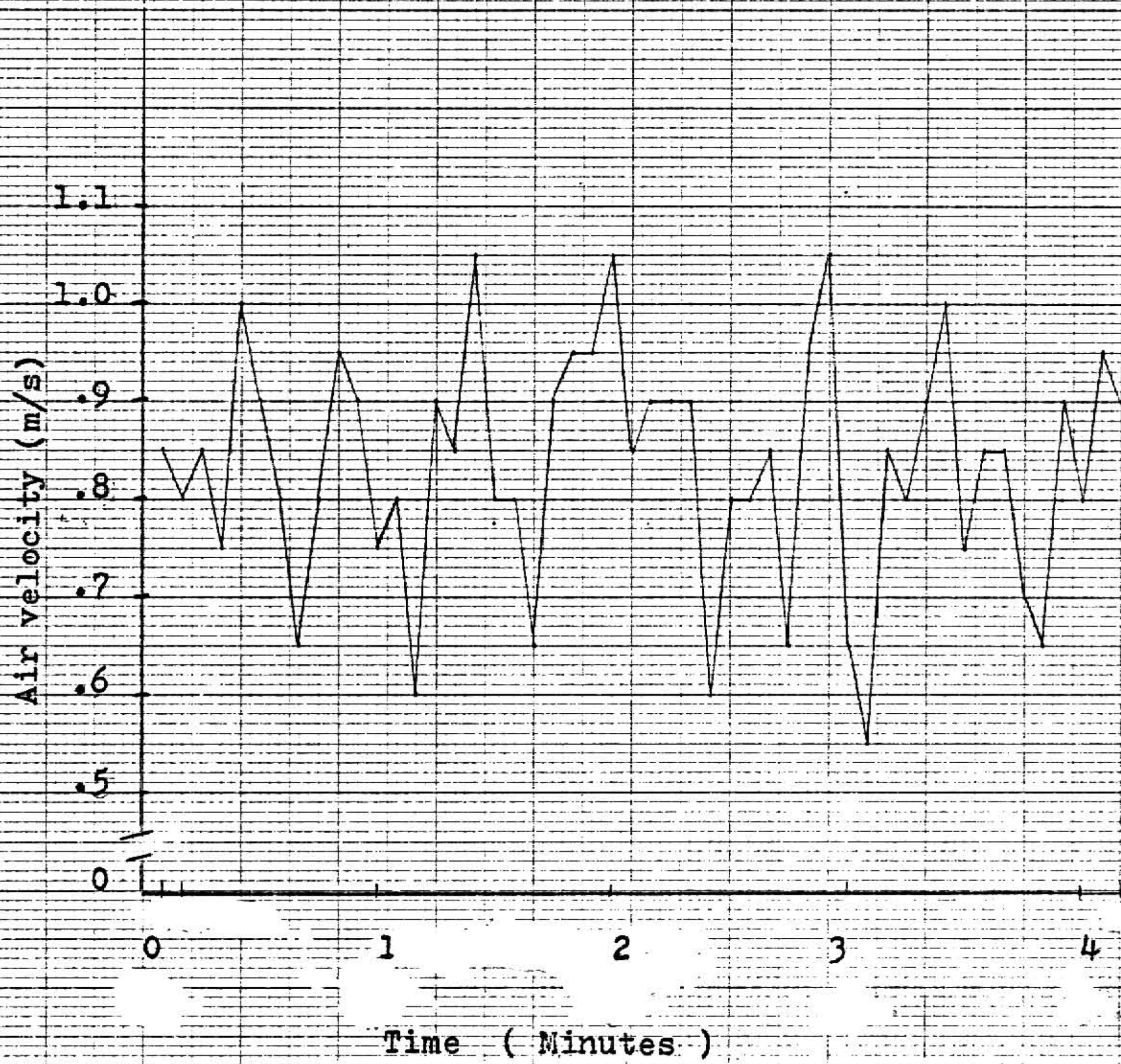

Figure 10 Air velocity readings for fan fixed at 3.2 meters.

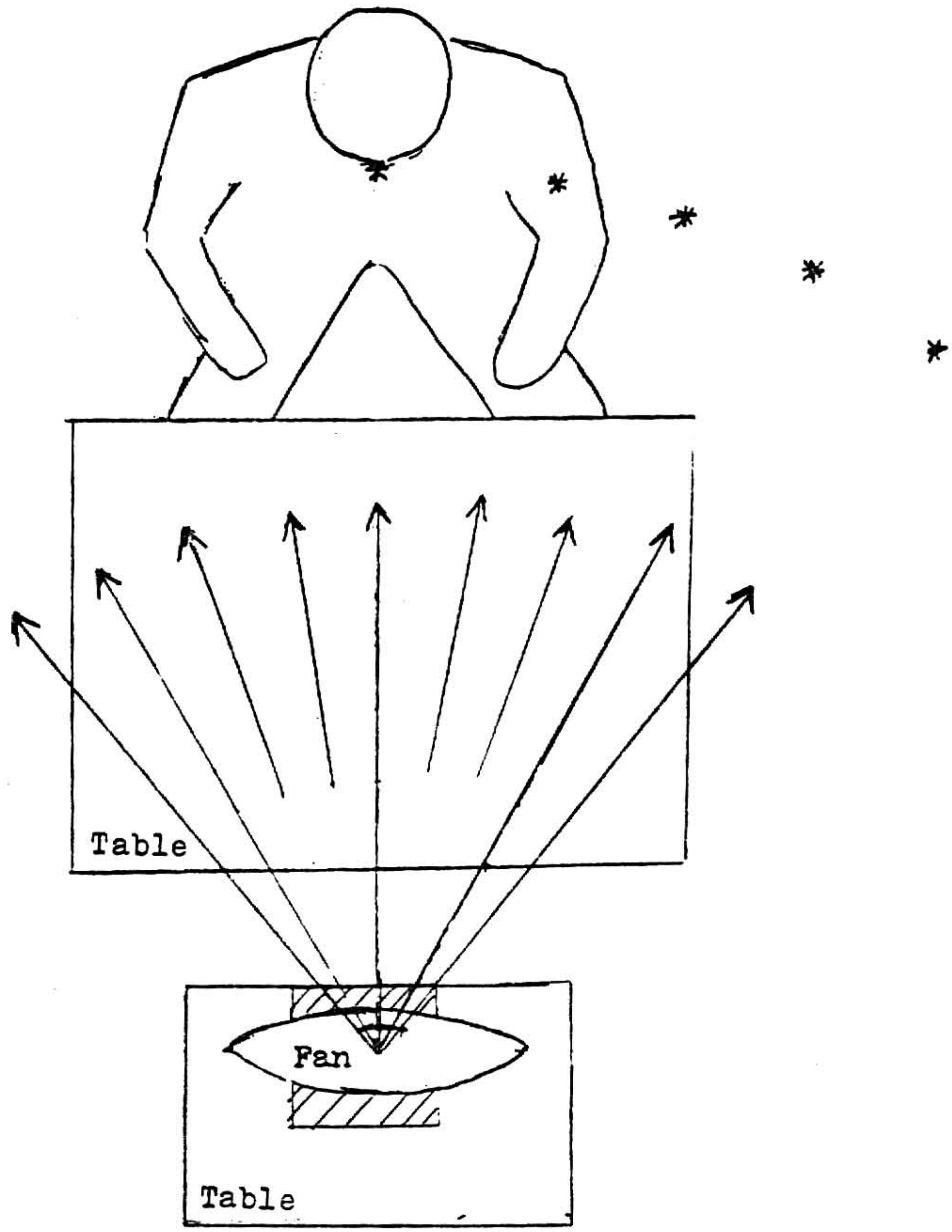

Figure 11 Measuring the air velocity while the fan is in an oscillating position. (*) Point where air velocity was measured.

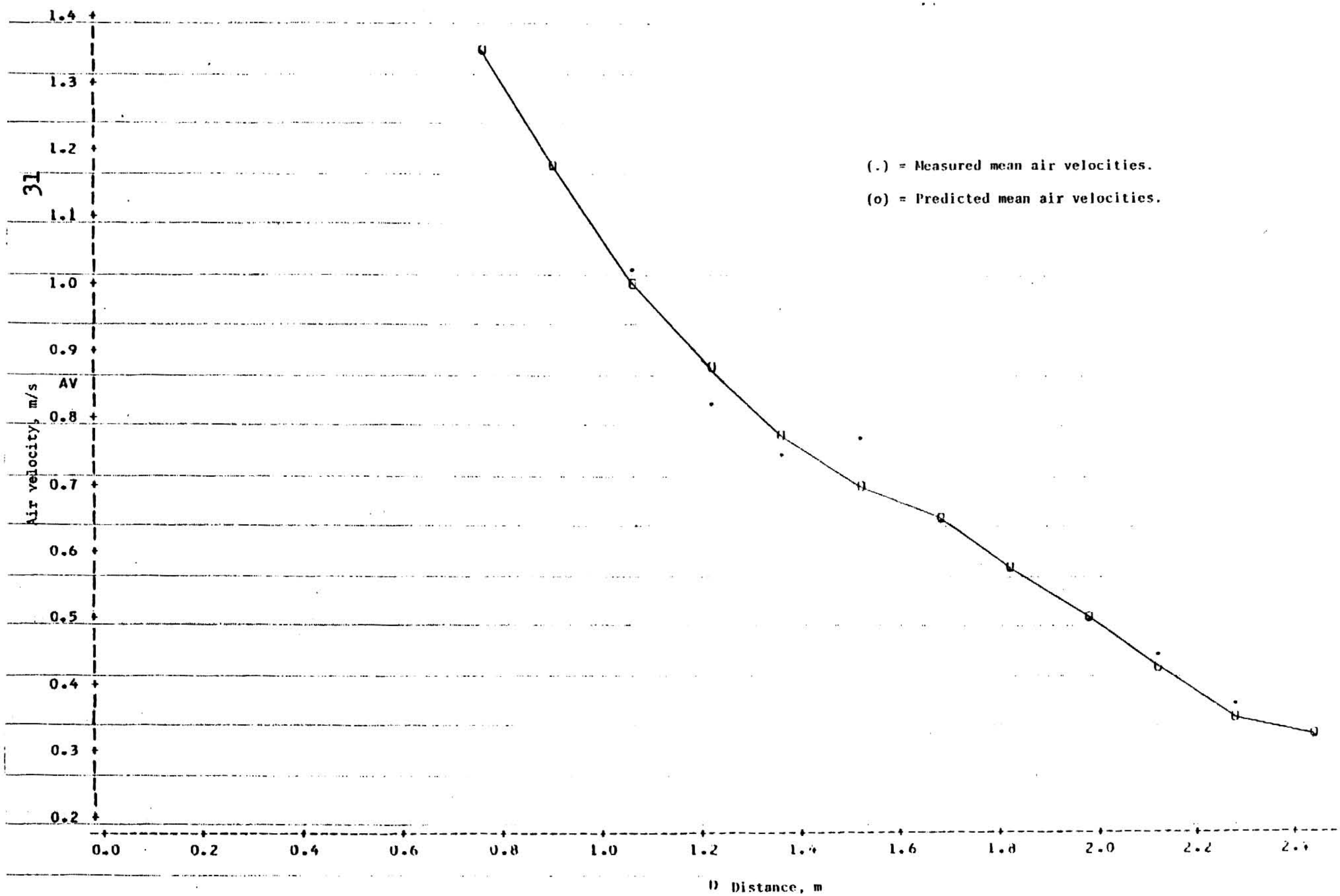

Figure 12 Mean air velocity of the oscillating fan at different distaces.

TABLE 4

Maximum mean air velocity at different distances for the fan in an oscillating position.

Distance (meters)	Maximum mean air velocity (m/s)	Standard deviation
.76*	1.34	
.91	1.17	.111
1.07	1.03	.170
1.22	.83	.190
1.37	.76	.117
1.52	.77	.117
1.68	.64	.137
1.83	.57	.137
1.98	.50	.154
2.13	.44	.116
2.29	.37	.141
2.44	.32	.118

*) Some of the readings are not accurate because of the limited range of the velometer.

imately 2.2 meters away from the subject. For a maximum velocity of .8 m/s the fan should be approximately 1.4 meters away from the subject. For a maximum velocity of 1.2 m/s the fan should be approximately .9 meters away from the subject. Readings for the maximum velocity of .8 m/s are plotted in Figure 13.

Tables 5 and 6 and Figures 14, 15 and 16 show the mean air velocity readings at every second of the oscillating cycle for two cases:

1- When the subject is seated in the middle of the oscillating cycle. Here the subject is exposed to a constant air flow which varies with the cycle.

2- When the subject is seated at the edge of the oscillating cycle. Here the subject is also exposed to a somewhat constant air flow, but the difference between each air velocity at every second of the cycle becomes greater than when the subject is seated in the middle of the cycle.

For the case when the subject is seated in the middle of the oscillating cycle a mean for the air velocity can be found which represents a percentage of the maximum mean air velocity. From Table 5 and Figures 14, 15 and 16 it can be seen that the mean air velocities for the maximum air velocities of .4, .8, and 1.2 m/s are .3, .5, and .7 m/s respectively. These air velocities represent another

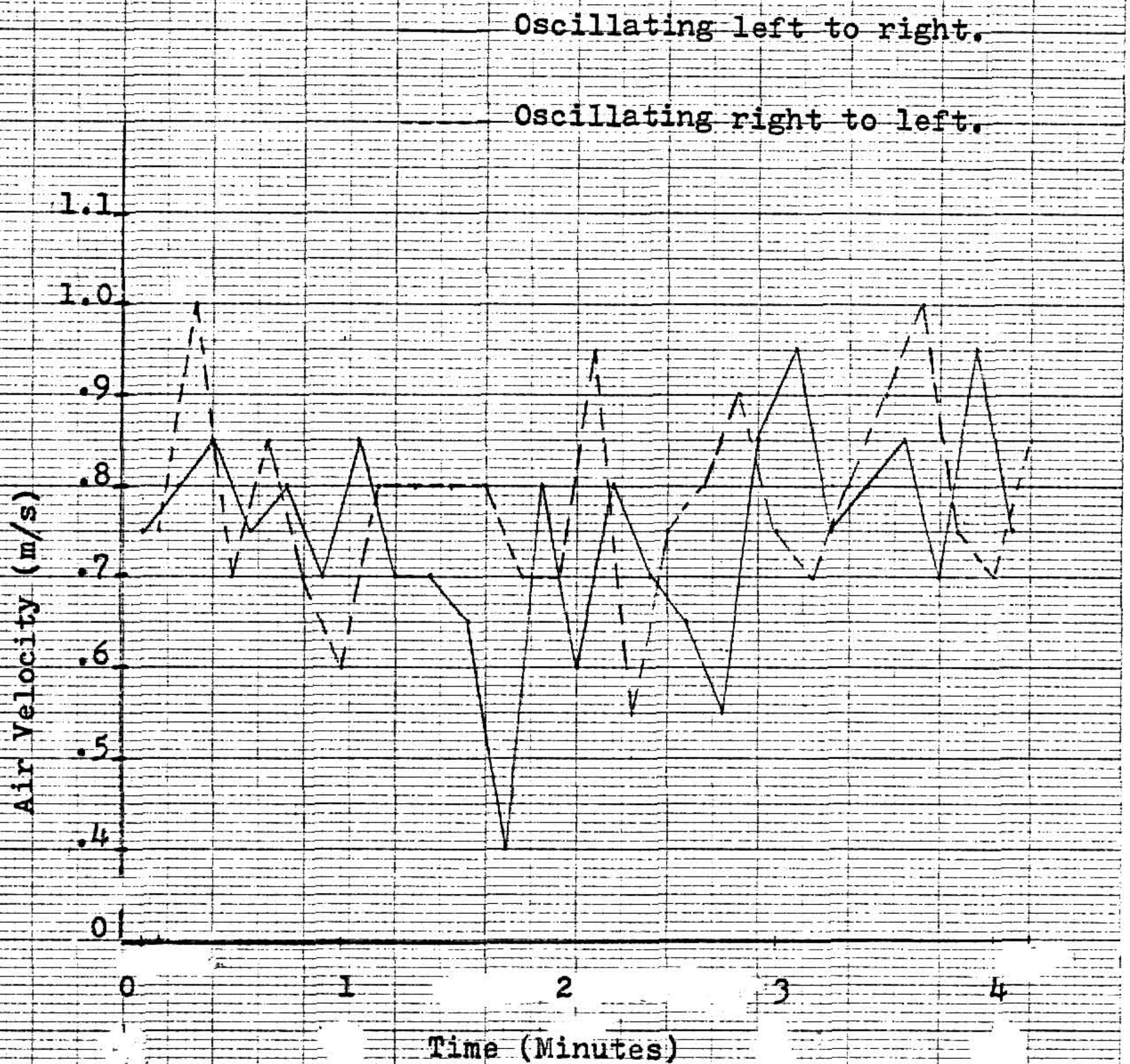

Figure 13 Maximum air velocity readings at 1.4 meters for fan oscillating and facing the subject.

TABLE 5

Air velocity readings for the oscillating fan when the subject is seated in the middle of the fan cycle.

Fan cycle	Distance (meters)		
(seconds)	.9	1.4	2.2
1	.38	.33	.34
2	.26	.25	.31
3	1.07	.63	.24
4	1.13	.85	.40
5	.64	.77	.37
6	.31	.29	.35
7	.16	.27	.29
8	1.01	.61	.24
9	1.12	.77	.47
10	.81	.68	.37
Mean	.68	.54	.34

TABLE 6

Air velocity readings for the fan oscillating when the subject is seated at the edge of the fan cycle.

Fan cycle	Distance (meters)		
(seconds)	.9	1.4	2.2
1	-	.85	.38
2	1.23	.72	.31
3	1.21	.71	.30
4	.94	.06	.03
5	.0	.06	.02
6	.0	.0	.04
7	.03	.04	.03
8	.52	.20	.20
9	.80	.60	.37
10	-	.81	.43

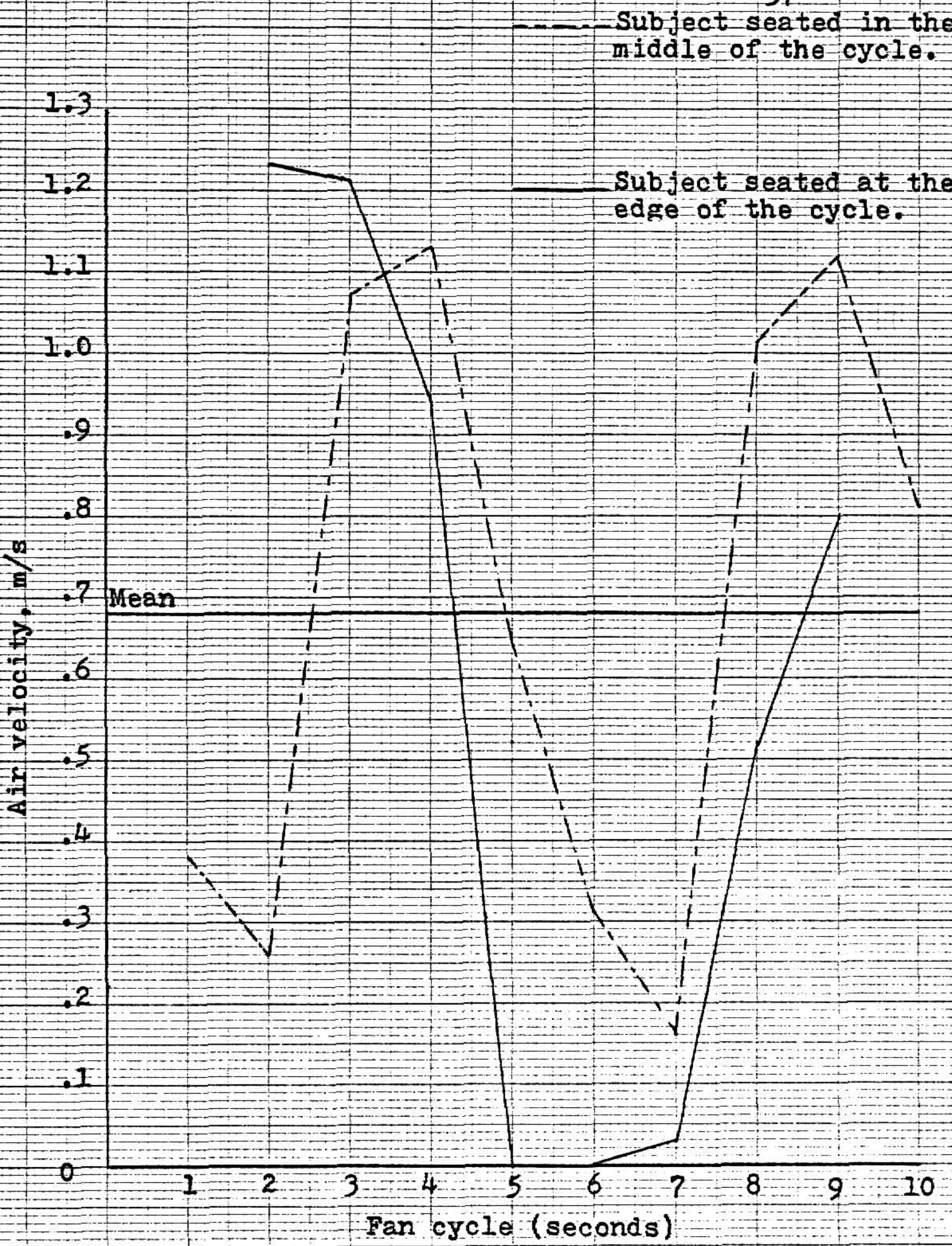

Figure 14 Mean air velocity on subject as a function of time from an oscillating fan at .9 meters from the subject.

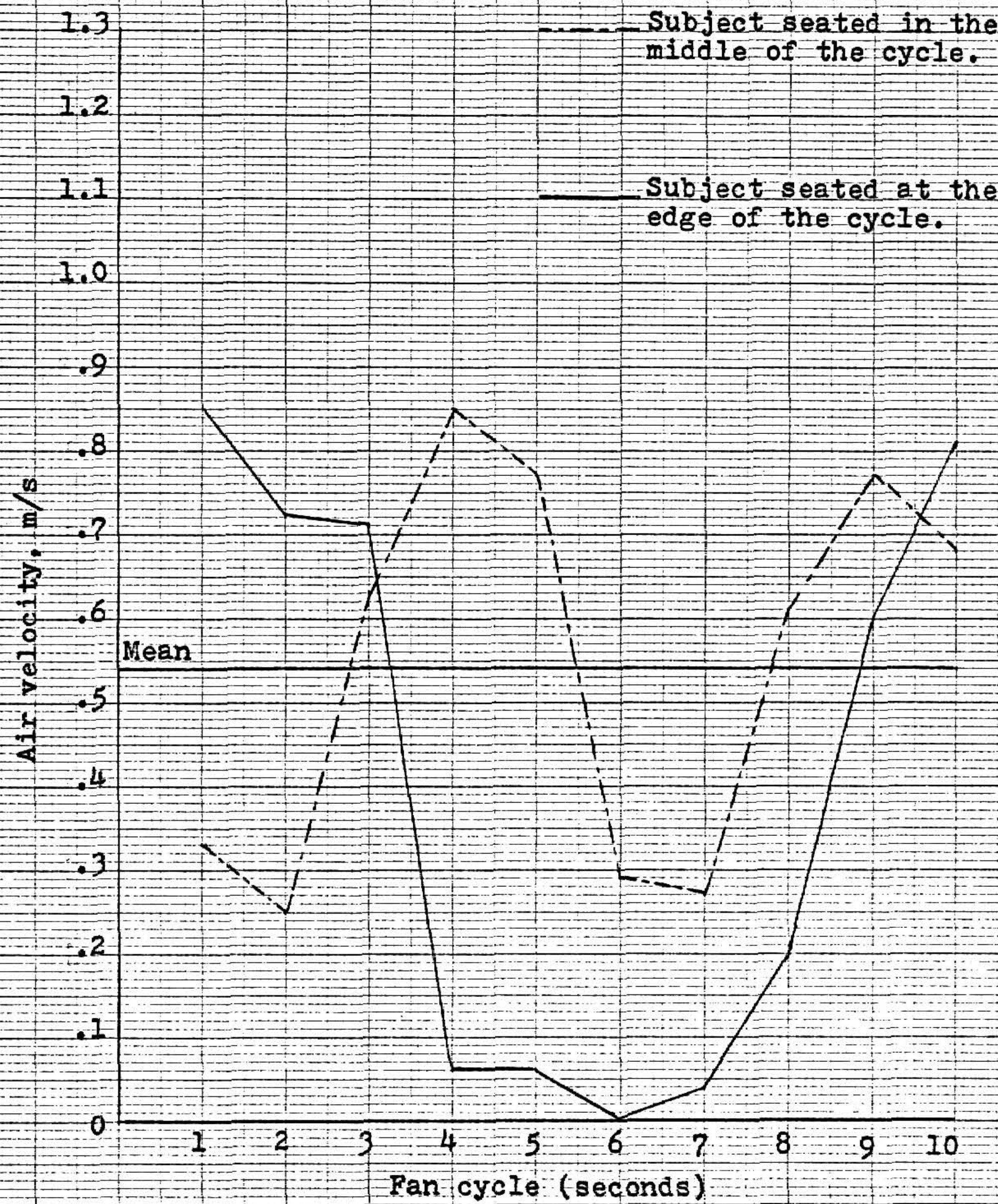

Figure 15 Mean air velocity on subject as a function of time from an oscillating fan at 1.4 meters from the subject.

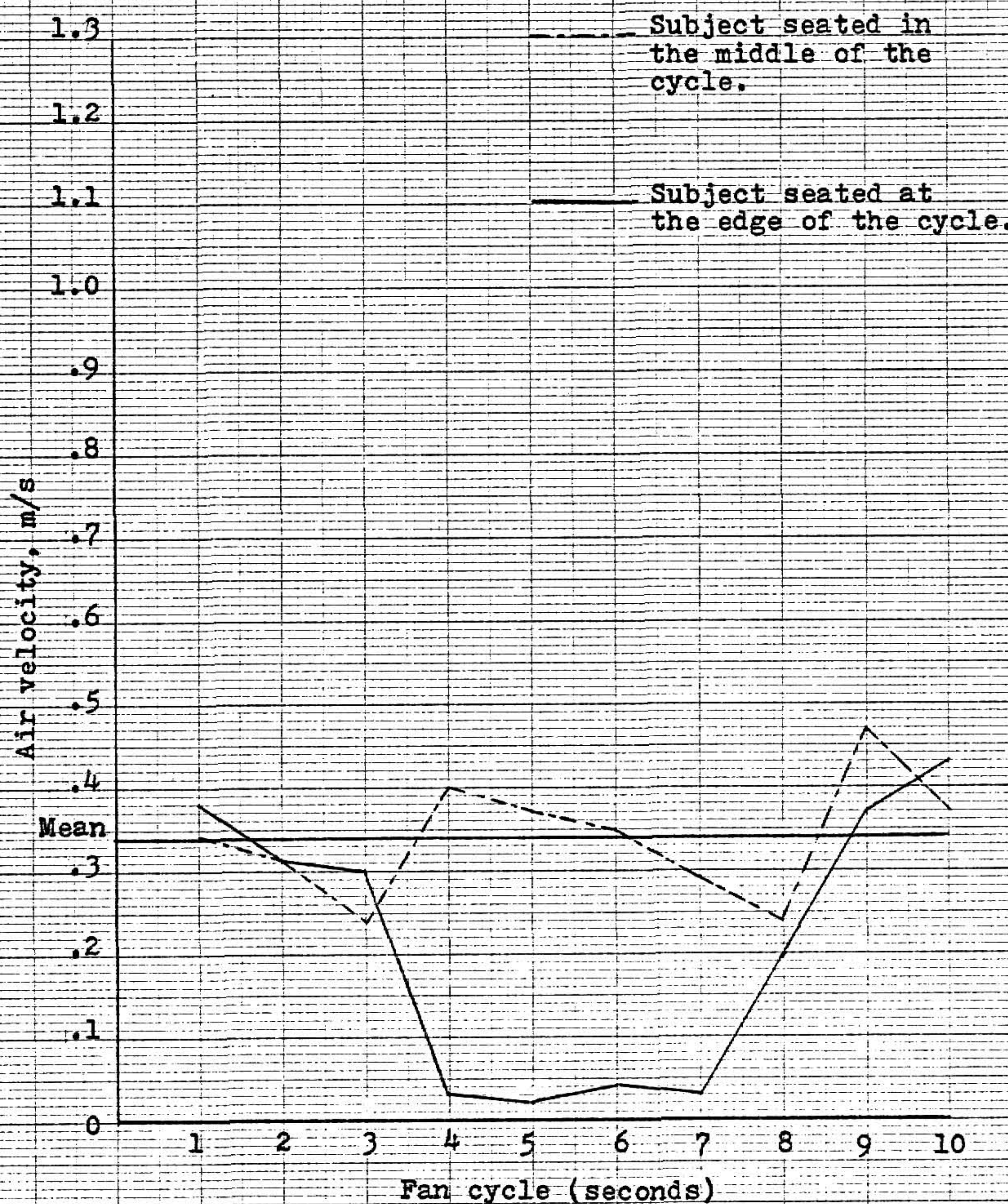

Figure 16 Mean air velocity on subject as a function of time from an oscillating fan at 2.2 meters from the subject.

TABLE 7

Air velocity readings at different angles for the oscillating fan.*

Angle (degrees)	Air velocity (m/s) .4	.8	1.2
0	.93	1.38	-**
10	.64	1.07	-
20	.53	.89	1.28
30	.46	.85	1.15
40	.44	.76	1.17
50	.46	.85	1.15
60	.53	.89	1.28
70	.64	1.07	-
80	.93	1.38	-

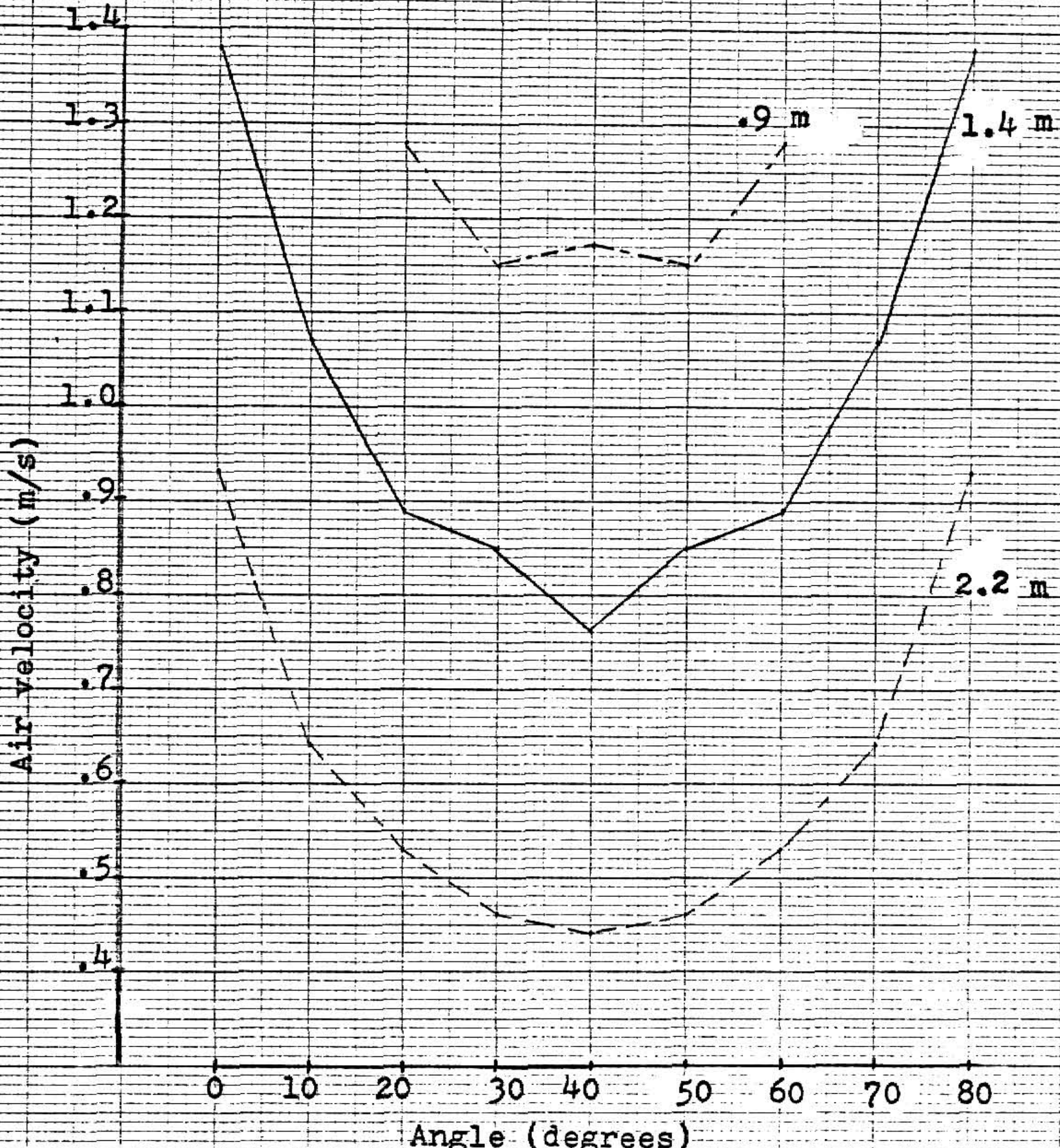

Figure 17 Air velocity readings at different angles for the oscillating fan at .9, 1.4, and 2.2 m distamce.

TABLE 8

Air velocity measurements at the subject's feet.

Air velocity (m/s)	Fan Distance (meters)	Air velocity at feet (m/s)	
		Fixed	Oscillating
.4	2.2	-	.03
	4.5	.30	-
.8	1.4	-	-
	3.2	.34	-
1.2	.9	-	-
	2.1	.17	-

interpretation for the maximum velocities of the oscilling fan.

Air velocity readings were taken at every 10 degrees of the oscillating cycle (readings were averaged). See Table 7 and Figure 17. Air velocity measurements also were taken at the subject's feet, see Table 8.

Noise measurements were taken for every condition of the experiment. The noise measurements for the chamber with no fan and the humidifier off was 42 dBA. Noise measurements for the chamber with no fan and the humidifier on was 53 dBA. Noise measurements while the fan was fixed or oscillating was from a minimum of 52 dBA to a maximum reading of 58 dBA, see Table 9.

A table (.8 x .8 x .7 meters) and a chair were used for each subject. Each fan was put on a separate table (.6 x .6 x .8 meters) and facing the subject. The distance between the subject's face and the floor averaged 1.1 meters; the height between the center of the fan and the floor was 1.1 meters.

TABLE 9

Noise measurements.

Fan condition	Air velocity (m/s)	Noise (dBA) Subject seated near humidifier	Subject seated away from humidifier
No Fan	.0	53	52
Fan Oscillating	.4	53	52
	.8	56	55
	1.2	58	57
Fan Fixed	.4	53	52
	.8	53	52
	1.2	53	52

RESULTS

Thermal sensation ballot: Votes from the thermal sensation ballot are shown in Table 10.

An analysis of variance was performed on the votes obtained; see Table 11. All factors and interactions were significant except the temperature and fan condition interaction which was not significant.

Replications of the experimental conditions were not significantly different, see Table 12.

Duncan's multiple range test for the "still air" conditions shows that they are not significantly different, see Table 13.

Table 14 shows Duncan's multiple range test for the various means. Means of the different temperatures show a significant difference between them. The fan condition means show that there was no significant difference between the fan fixed at a velocity of .4 m/s and the "still air" conditions. The "still air" conditions and the fan fixed at a velocity of .4 m/s were significantly different from the remaining fan conditions. Table 15 shows the difference between the mean votes for the subjects.

Figures 18, 19 and 20 show the different fan conditions at different temperatures. They show that the oscillating fan is preferred over the fixed fan. The figures also show that subjects feel cooler at higher

TABLE 10

Votes obtained from the thermal sensation ballot.

Temperature								25.6 C									
			(0.3)		(0.5)		(0.7)		(0.4)		(0.8)		(1.2)				MEAN
	NF	NF	F01	F01	F02	F02	F03	F03	FF1	FF1	FF2	FF2	FF3	FF3	NF	NF	TOTAL
1	5	5	4	4	4	4	4	4	5	5	4	4	4	4	5	5	
2	5	5	5	5	5	5	5	4	5	5	5	5	5	5	5	5	
3	5	5	5	5	4	4	5	5	5	5	4	4	4	4	6	6	
4	6	6	4	5	5	4	4	4	4	5	5	5	4	4	6	5	
5	5	5	4	5	4	4	4	4	5	5	4	4	4	4	5	5	
6	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	
7	5	5	4	3	3	3	3	3	5	6	4	3	4	3	6	6	
8	5	6	5	4	4	4	3	4	5	6	6	5	4	6	7	8	
MEAN	4.9		4.3		3.9		3.9		4.8		4.3		4.0		5.4		4.4

Temperature								27.8 C									
			(0.3)		(0.5)		(0.7)		(0.4)		(0.8)		(1.2)				MEAN
	NF	NF	F01	F01	F02	F02	F03	F03	FF1	FF1	FF2	FF2	FF3	FF3	NF	NF	TOTAL
1	6	5	4	4	5	5	4	3	5	5	4	5	3	3	5	6	
2	5	5	5	5	5	5	5	5	5	6	5	5	5	5	5	5	
3	5	6	6	5	5	5	5	5	6	6	6	6	5	5	7	6	
4	5	6	5	4	5	5	4	5	5	5	5	5	4	4	5	6	
5	6	6	5	5	6	6	6	6	5	6	6	6	6	5	6	6	
6	8	8	5	5	6	6	5	6	6	7	5	5	5	5	6	7	
7	5	6	4	3	3	3	3	3	5	5	3	3	4	4	6	6	
8	6	7	5	6	4	4	4	4	7	7	4	4	4	4	7	7	
MEAN	5.9		4.8		4.9		4.6		5.7		4.8		4.4		6.0		5.1

TABLE 10 (continued)

Temperature								30 C								
			(0.3)		(0.5)		(0.7)		(0.4)		(0.8)		(1.2)			MEAN
	NF	NF	F01	F01	F02	F02	F03	F03	FF1	FF1	FF2	FF2	FF3	FF3	NF	NF	TOTAL
1	7	8	5	4	5	4	5	6	6	6	4	4	4	4	4	4	
2	6	6	6	6	6	5	5	5	6	7	5	5	5	5	6	6	
3	7	7	6	6	6	6	6	5	6	6	6	6	5	6	7	7	
4	7	7	5	5	5	5	4	5	6	6	5	5	5	5	6	6	
5	6	6	5	5	5	5	5	5	7	6	6	5	6	5	5	6	
6	7	7	4	3	4	4	5	4	5	4	5	5	4	4	5	7	
7	7	8	6	5	4	4	3	4	6	6	6	6	4	4	7	7	
8	6	6	6	5	5	5	6	6	7	8	7	6	8	6	5	4	
MEAN	6.8		5.1		4.9		4.9		6.1		5.4		5.0		5.8		5.5

TABLE 11

Analysis of variance for the votes from the thermal sensation ballot.

Source	d.f.	Mean square	F-value
T	2	18.69	49.18**
FC	7	8.35	21.97**
S	7	3.50	9.21**
T x FC	14	.43	1.13
T x S	14	2.31	6.08**
FC x S	49	.56	1.47*
ERROR	98	.38	
Total	191		

** $\alpha \leqslant 1\%$

* $\alpha \leqslant 5\%$

TABLE 12

Duncan's multiple range test on the votes for replications from the thermal sensation ballot.*

Replications	1	2
Mean vote	5.0	5.0
	AAAAAAAAAA	

* Means with the same letter are not significantly different.

TABLE 13

Duncan's multiple range test for the values of the still air conditions from the thermal sensation ballot.*

"still air"	End	Start
Mean vote	5.7	5.9
	AAAAAAAAAAAAA	

* Means with the same letter are not significantly different.

TABLE 14

Duncan's multiple range test on votes for temperatures and fan conditions from the thermal sensation ballot (4 = Slighly cool, 5 = Neutral, and 6 = Slightly warm).*

Temperature (C)	25.6	27.8	30
Mean vote	4.4	5.1	5.5
	C	B	A

	Air velocity, m/s							
	Osc.	Fix.	Osc.	Osc.	Fix.	Fix.	Start	End
Fan condition	.7	1.2	.5	.3	.8	.4	.2	.2
Mean vote	4.5	4.5	4.6	4.7	4.8	5.5	5.7	5.9
	BBBBBBBBBBBBBBBBBBBBBBB					AAAAAAAAAAAAAA		

* Means with the same letter are not significantly different.

TABLE 15

Duncan's multiple range test for votes of the subjects from the thermal sensation ballot.*

Subjects	7	6	1	4	2	5	8	3
Mean vote	4.6	4.6	4.6	5.0	5.2	5.2	5.4	5.5
	C	C	C		A	A	A	A
				B	B	B		

* Means with the same letter are not significantly different.

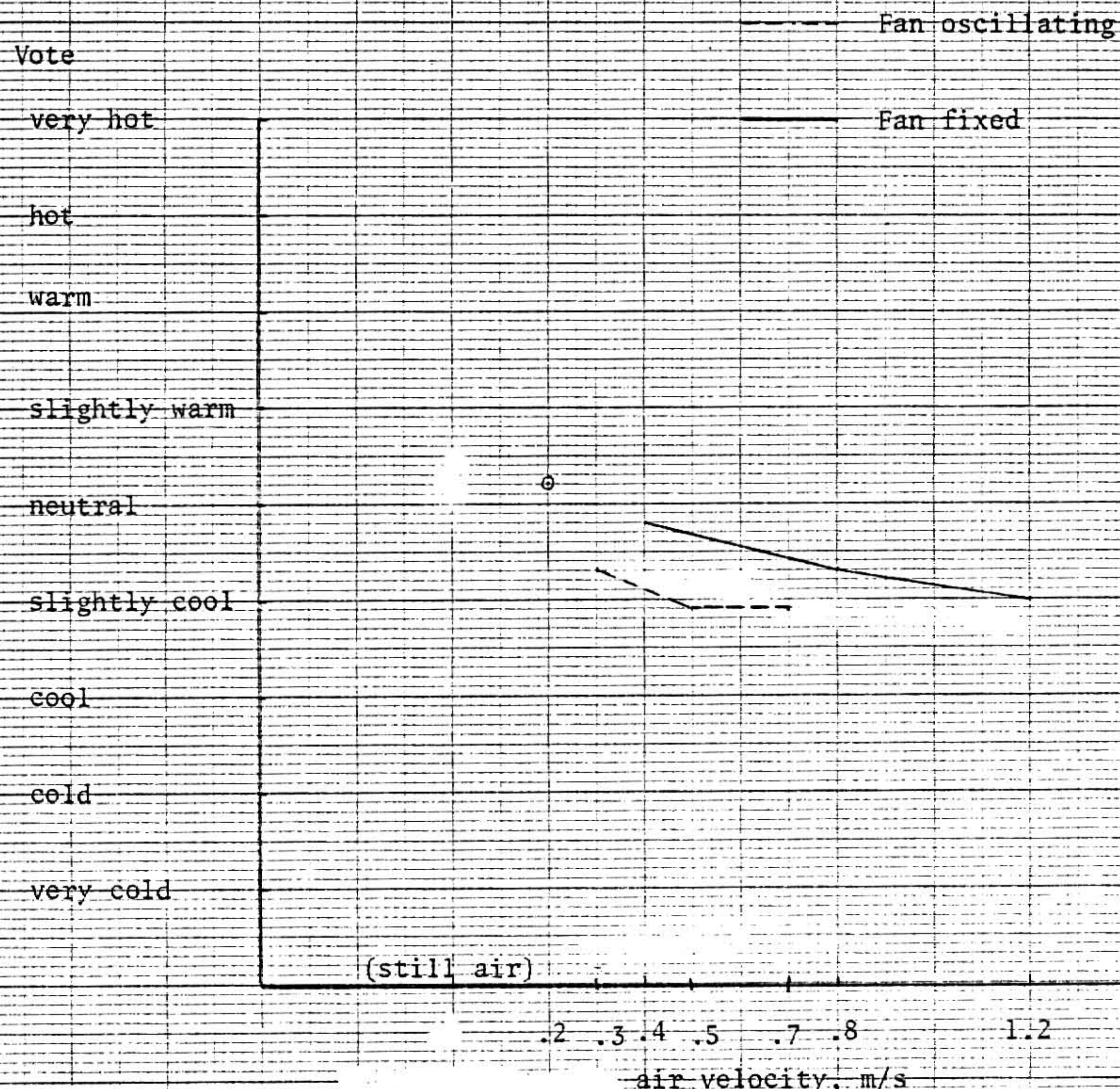

Figure 18 Votes for air velocity from an oscillating and a fixed fan at a temperature of 25.6 C from the THS ballot.

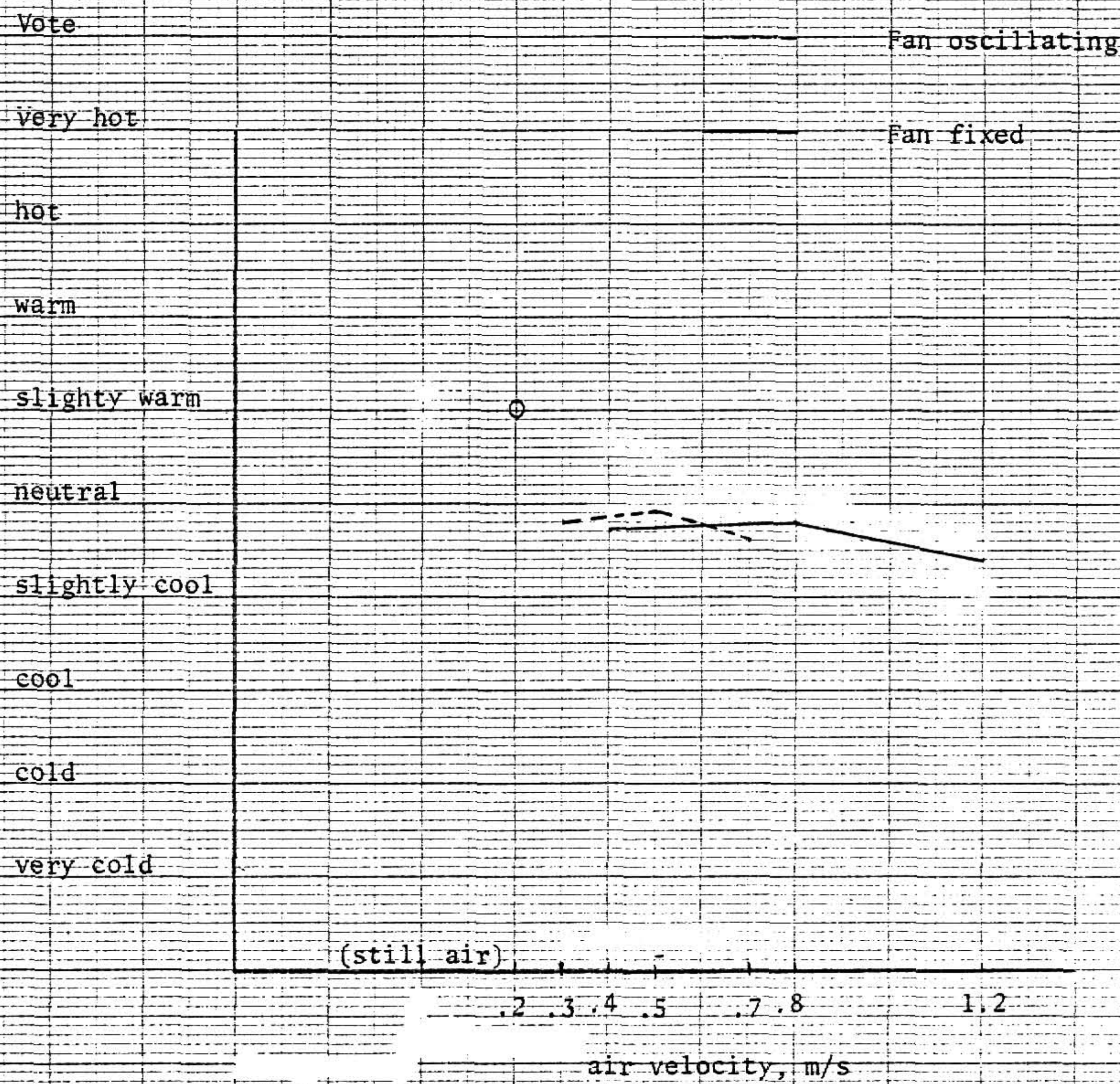

Figure 19. Votes for air velocity from an oscillating and fixed fan at a temperature of 27.8 C from the THS ballot.

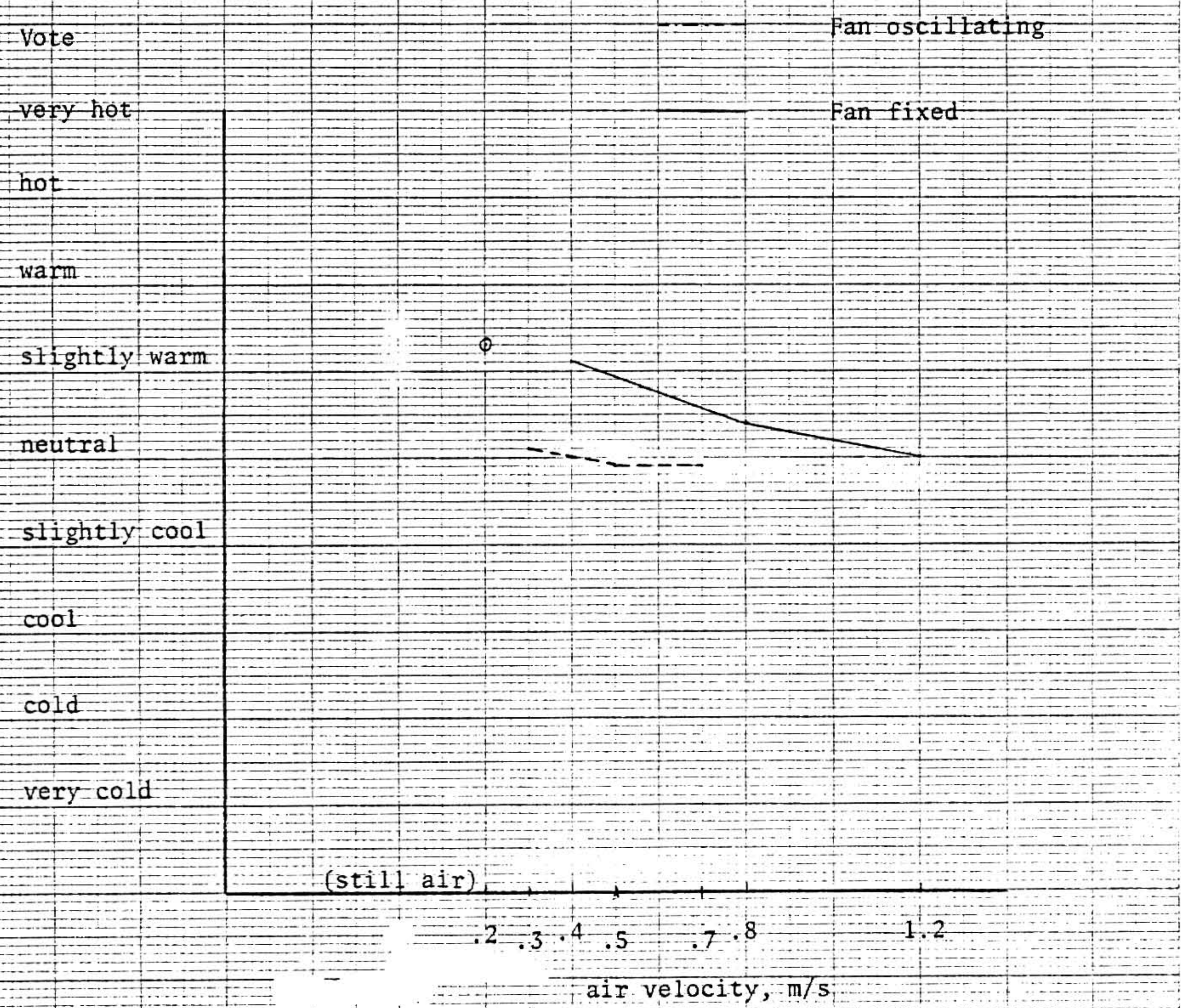

Figure 20. Votes for air velocity from an oscillating and fixed fan at a temperature of 30 C from the THS ballot.

air velocities. Figure 21 shows an overall look at the difference between the oscillating fan and the fixed fan.

Figures 22, 23, 24, and 25 show the different conditions of the fan at different temperatures.

An analysis of variance was performed on the votes for the oscillating fan and the votes for the fixed fan. See Tables 16 and 17. Temperature was significant for both the fixed and oscillating fan but air velocity was significant only for the fixed fan. The interaction between the air velocity and temperatures was not significant for either fan.

Table 18 shows the Duncan's multiple range test for the temperatures with the oscillating fan. Temperatures of 30 and 27.8 C were not significantly different. Table 19 and 20 show Duncan's multiple range test for the mean votes of the fixed fan. Temperatures are significantly different. Although air velocities of .8 m/s and 1.2 m/s are not significantly different, they are significantly different from .4 m/s.

Figure 26 shows the air velocities for the fixed fan at different temperatures. The figure shows that higher air velocities generates lower votes.

Semantic differential scale ballot: An analysis of factors was performed on the votes obtained from the semantic differential scale ballot by the use of a SAS

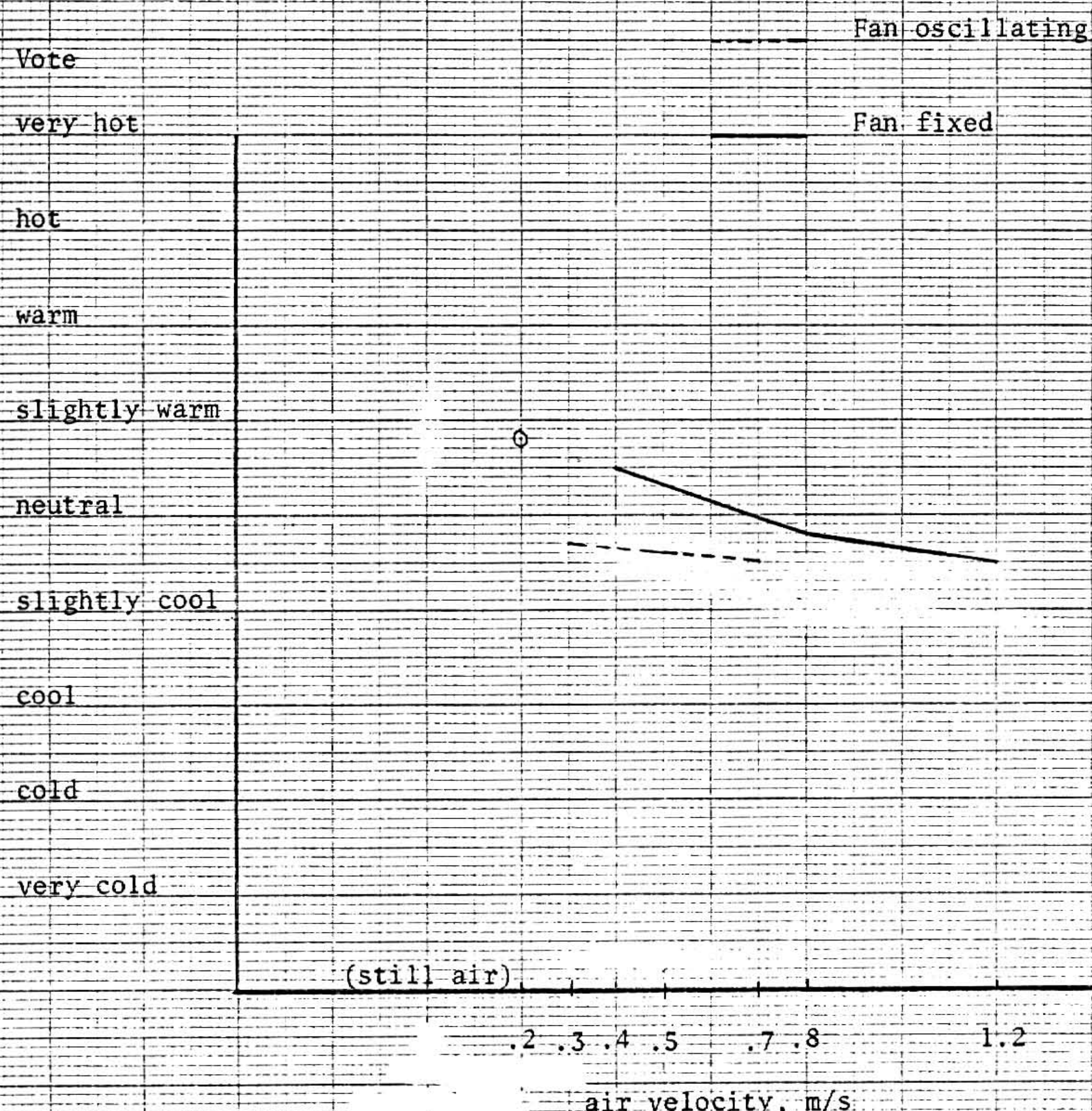

Figure 21. Overall votes for the oscillating and fixed fan from the THS ballot.

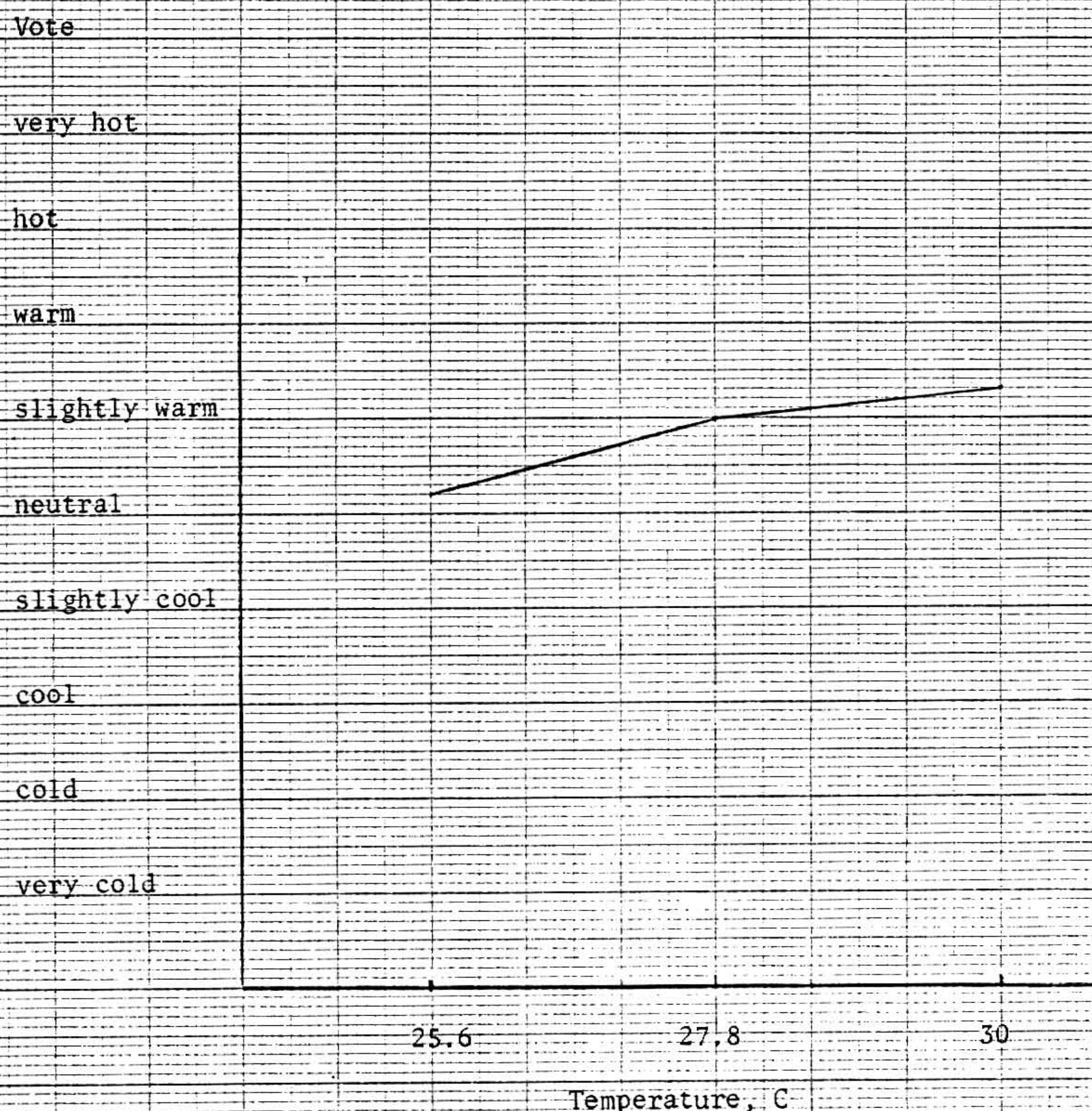

Figure 22. Votes for the "still air" condition at different temperatures from the THS ballot.

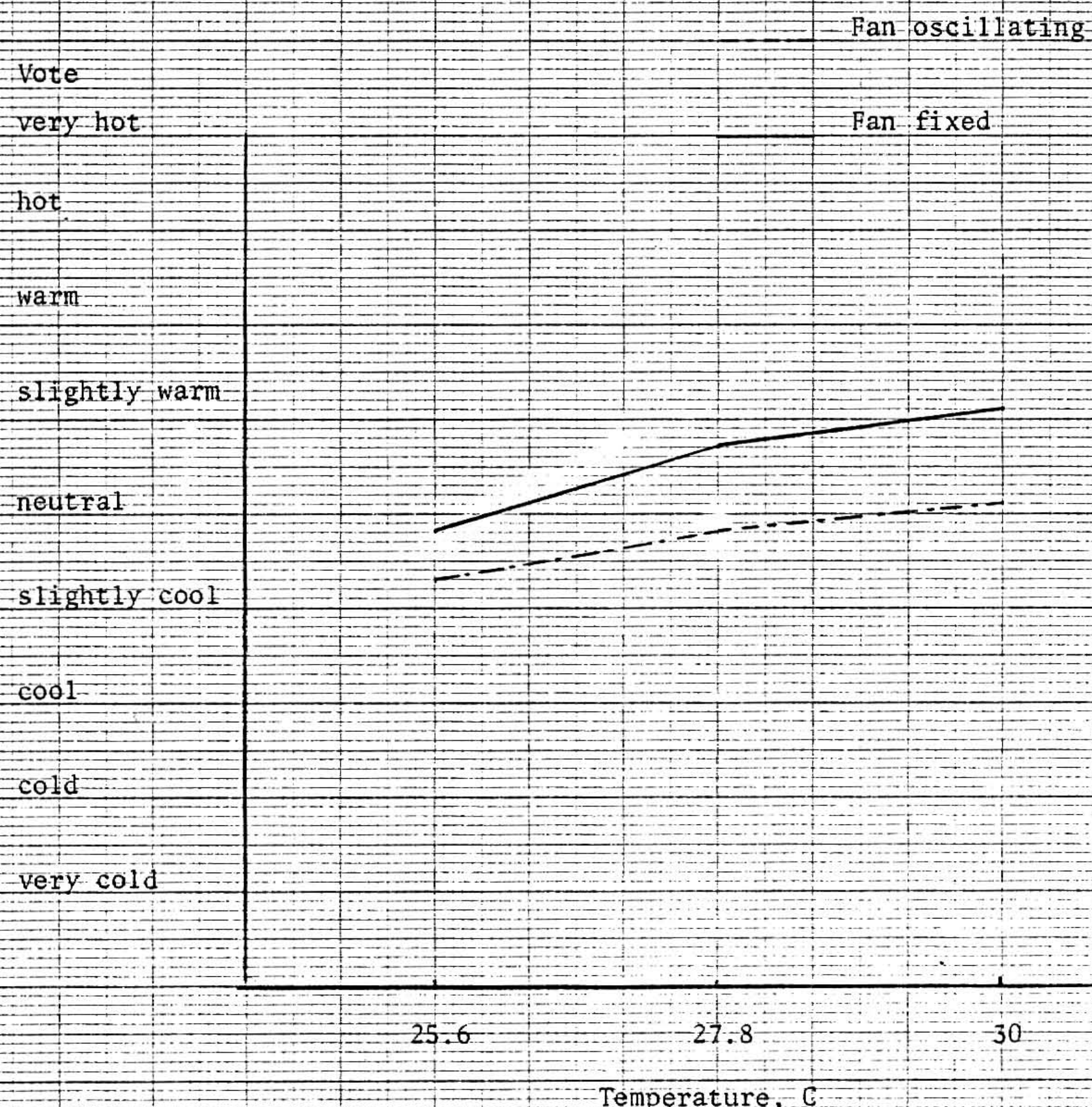

Figure 23. Votes for velocities of .4 m/s fan fixed and .3 m/s from fan oscillating at different temperatures from the THS ballot.

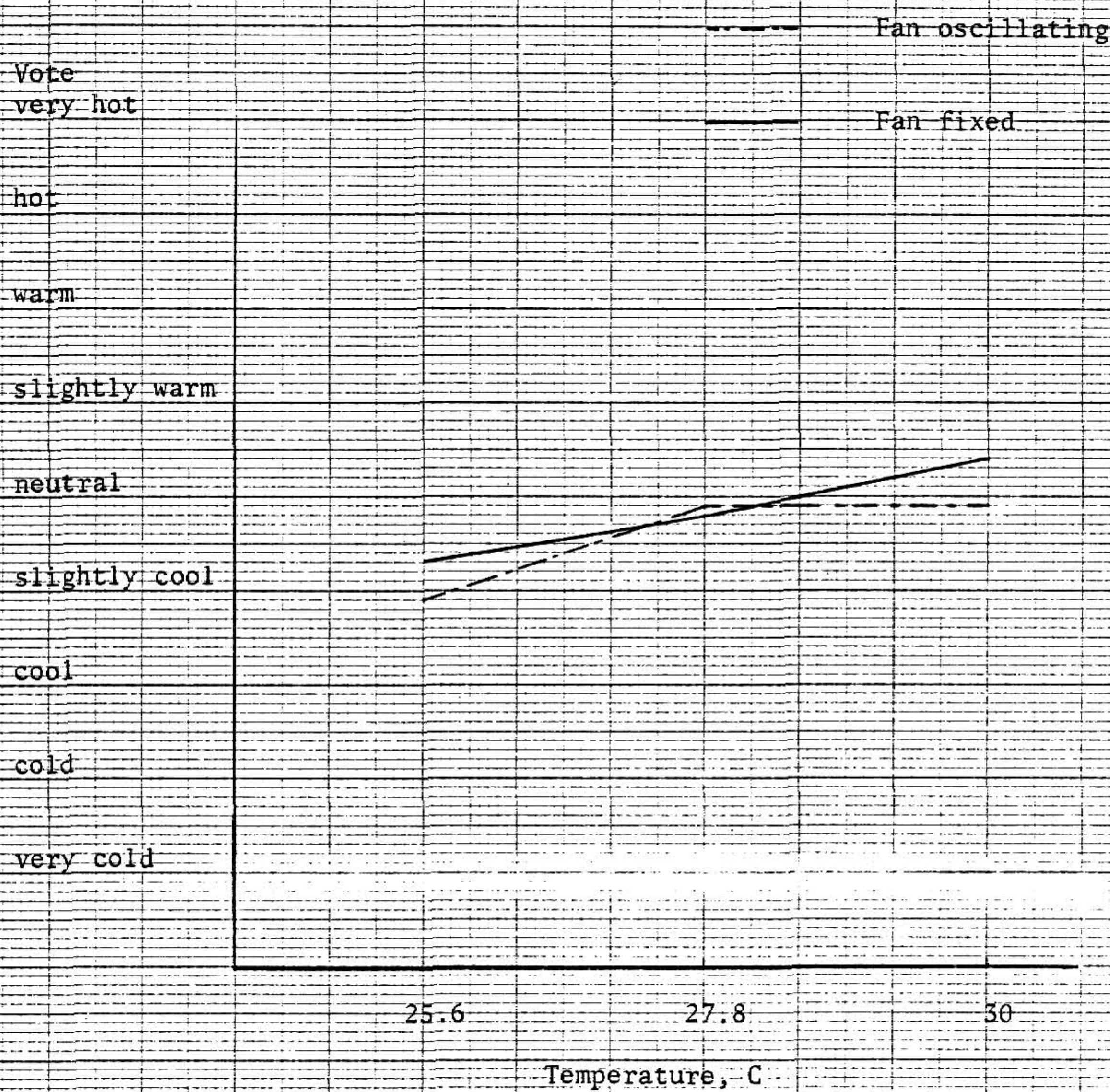

Figure 24. Vote for velocities of .8 m/s fan fixed and .5 m/s fan oscillating at different temperatures from the THS ballot.

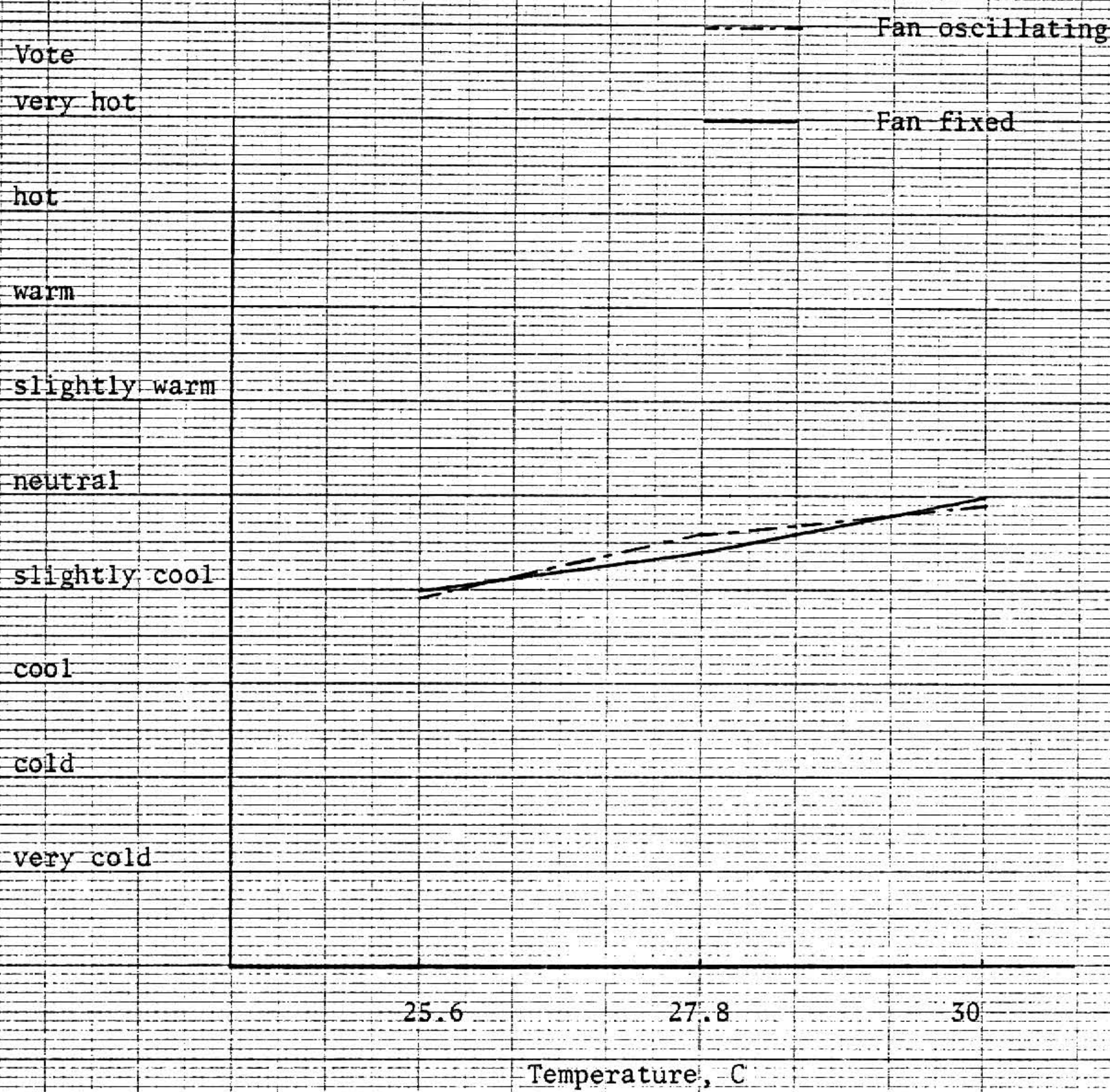

Figure 25. Votes for velocities of 1.2 m/s fan fixed and .7 m/s fan oscillating at different temperatures from the THS ballot.

TABLE 16

Analysis of variance for votes on the oscillating fan from the thermal sensation ballot.

Source	d.f.	Mean Square	F-value
T	2	5.93	29.65**
AV	2	.38	1.90
S	7	2.72	13.60**
T x AV	4	.14	.70
T x S	14	.83	4.15**
AV x S	14	.29	1.45
ERROR	28	.20	
Total	71		

**$\alpha \leq$ 1%

*$\alpha \leq$ 5%

TABLE 17

Analysis of variance for votes on the fixed fan from the thermal sensation ballot.

Source	d.f.	Mean square	F-value
T	2	7.90	21.35**
AV	2	7.09	19.16**
S	7	2.31	6.24**
T x AV	4	.11	.30
T x S	14	1.02	2.76*
AV x S	14	.25	.68
ERROR	28	.37	
Total	71		

** $\alpha \leqslant 1\%$

* $\alpha \leqslant 5\%$

TABLE 18

Duncan's multiple range test for votes of the oscillating fan for temperatures from the thermal sensation ballot.*

Temperature (C)	25.6	27.8	30
Mean vote	4.0	4.7	5.0
	B	AAAAAAAAAAAAAA	

* Means with the same letter are not significantly different.

TABLE 19

Duncan's multiple range test on votes for the fixed fan by temperature from the thermal sensation ballot.*

Temperature (C)	25.6	27.8	30
Mean vote	4.4	5.0	5.5
	C	B	A

* Means with the same letter are not significantly different.

TABLE 20

Duncan's multiple range test for votes of the fixed fan by air velocity from the thermal sensation ballot.*

Air velocity (m/s)	1.2	.8	.4
Mean vote	4.5	4.8	5.5
	BBBBBBBBBB		A

* Mean with the same letter are not significantly different

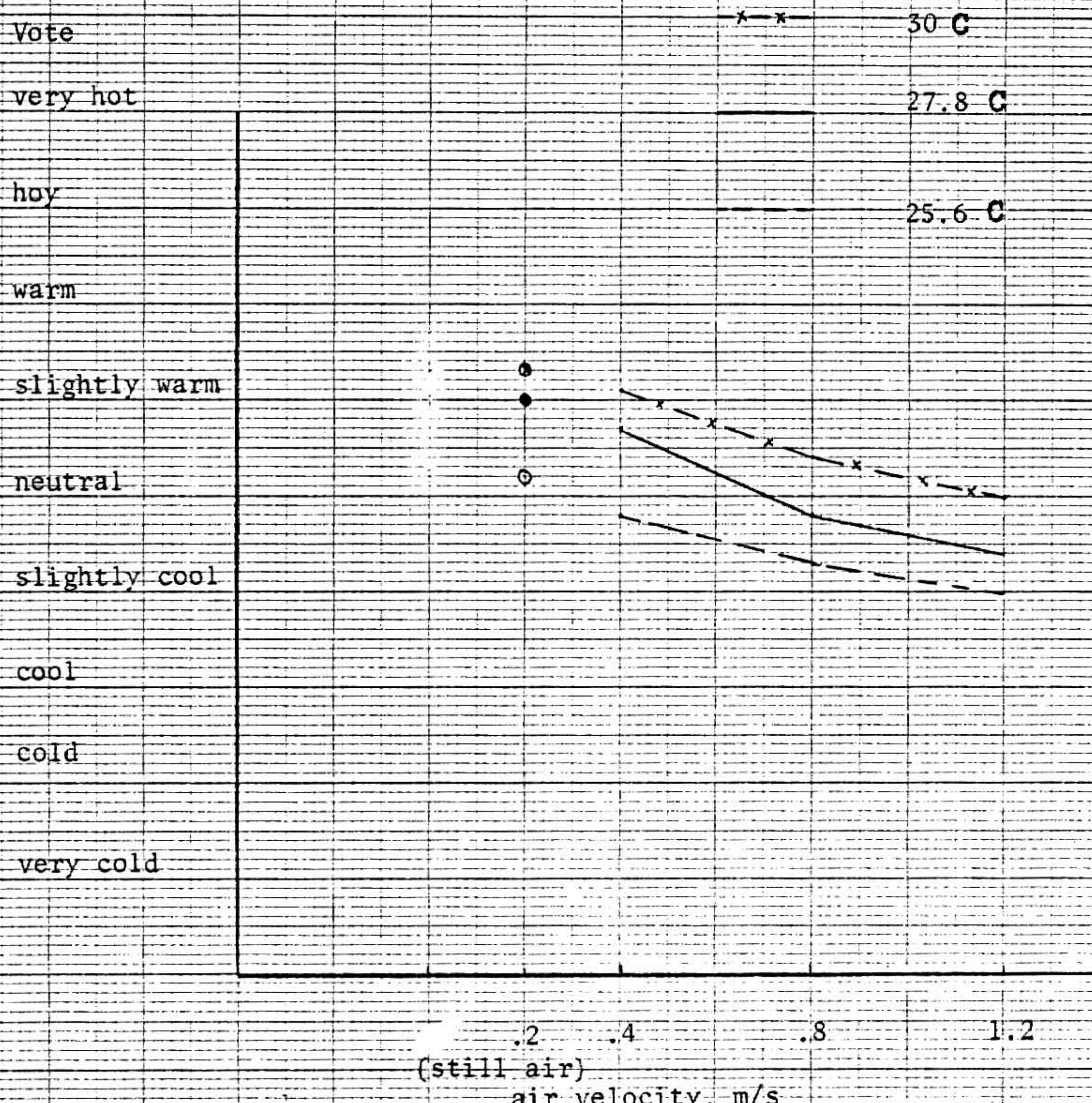

Figure 26. Air velocity of the fixed fan at different temperatures from the THS ballot.

program. The analysis generates weights (cofficients) for every category of the ballot; the weights generated can be seen in Table 21. Using the weights a percentage of votes were obtained for the experimental conditions, see Table 22.

An analysis of variance was performed on the percentages of votes, see Table 23. All factors and interactions were significant except the temperature and fan condition interaction which was not significant.

Replications for the experimental conditions were not significantly different, see Table 24.

Duncan's multiple range test for the "still air" conditions shows that they were not significant, see Table 25. Table 26 shows Duncan's multiple range test for the different mean percentages. Mean percentages of the different temperatures show a significant difference between them. The fan condition mean percentages show that there was no significant difference between the "still air" condition at the end of the experiment and the fan fixed at a velocity of .4 m/s. The remaining fan conditions were not significantly different, although they were significantly different from both the "still air" conditions and the fan fixed at a velocity of .4 m/s. Table 27 shows the difference between the mean percentage votes of the subjects.

TABLE 21

Weights obtained by the factor analysis for every category from the SDS ballot.

Category	Weight
Comfortable	.981
Good temperature	.976
Pleasant	.987
Good ventilation	.871
Acceptable	.966
Comfortable temperature	.979
Satisfied	.982

TABLE 22

Percentage of votes obtained from the semantic differential scale ballot.

Temperature 25.6 C

	NF	NF	(0.3) F01	(0.3) F01	(0.5) F02	(0.5) F02	(0.7) F03	(0.7) F03	(1.4) FF1	(1.4) FF1	(0.8) FF2	(0.8) FF2	(1.2) FF3	(1.2) FF3	NF	NF	MEAN TOTAL
1	12.5	18.0	14.3	0.0	18.0	12.5	28.7	23.4	3.6	1.8	0.0	0.0	12.5	10.7	0.0	12.5	
2	35.7	35.7	37.5	37.5	42.8	37.5	30.4	26.8	40.9	39.1	37.5	37.5	32.1	37.5	37.3	39.3	
3	50.0	50.0	39.1	37.5	37.5	37.5	37.5	37.5	39.1	44.6	32.0	34.1	28.4	34.1	51.9	60.7	
4	23.2	26.6	18.0	19.8	16.1	15.9	21.8	14.3	14.3	17.8	23.2	12.5	14.3	12.5	26.6	25.0	
5	17.8	17.9	0.0	0.0	0.0	9.1	0.0	0.0	12.5	12.5	14.1	14.1	0.0	0.0	20.9	17.5	
6	3.4	3.4	0.0	0.0	0.0	0.0	1.8	0.0	3.4	1.6	0.0	0.0	0.0	0.0	12.3	3.4	
7	55.4	46.2	26.4	20.9	13.7	19.2	13.9	13.7	58.9	46.1	29.8	17.5	17.3	10.1	80.7	78.8	
8	26.4	60.3	39.6	34.1	17.8	37.5	14.3	21.3	33.9	76.6	35.7	38.9	14.3	21.3	78.3	94.6	
MEAN	29.9		20.3		19.6		17.8		27.9		20.4		15.3		40.0		23.9

Temperature 27.8 C

	NF	NF	(0.3) F01	(0.3) F01	(0.5) F02	(0.5) F02	(0.7) F03	(0.7) F03	(1.4) FF1	(1.4) FF1	(0.8) FF2	(0.8) FF2	(1.2) FF3	(1.2) FF3	NF	NF	MEAN TOTAL
1	52.0	53.4	17.9	17.9	34.1	30.5	25.0	21.4	42.8	21.6	28.4	26.8	18.0	46.2	0.0	23.0	
2	37.5	43.0	44.8	44.6	37.5	39.3	41.1	37.5	43	48.4	37.5	39.3	37.5	37.5	44.6	37.3	
3	50.0	62.5	58.9	50.0	50.0	50.0	50.0	50.0	62.5	62.5	60.9	62.5	50.0	50.0	64.3	59.0	
4	30.2	26.6	14.3	14.3	16.1	12.5	14.3	12.5	25.0	23.2	15.9	21.4	12.5	12.5	26.6	26.6	
5	28.7	29.8	10.9	10.9	20.0	16.3	14.5	14.5	12.5	14.3	16.1	16.1	14.5	10.9	42.5	31.7	
6	96.6	98.4	12.5	12.5	23.4	23.4	12.5	12.5	25.0	37.5	12.5	12.5	12.5	8.9	40.7	53.5	
7	66,2	75.0	42.8	22.8	13.7	15.5	8.3	10.1	55.3	35.3	30.0	26.4	30.0	19.2	77.2	75.2	
8	55.4	80.3	43.0	85.7	26.6	25.0	25.0	25.0	57.3	71.4	26.6	25.0	26.8	25.0	78.4	85.7	
MEAN	55.3		31.6		27.1		23.4		40.0		28.6		25.9		47.9		35.0

TABLE 22 (continued)
Temperature

30 C

			(0.3)		(0.5)		(0.7)		(1.4)		(0.8)		(1.2)				MEAN
	NF	NF	F01	F01	F02	F02	F03	F03	FF1	FF1	FF2	FF2	FF3	FF3	NF	NF	TOTAL
1	55.7	87.5	32.2	10.7	73.2	30.5	37.5	41.2	64.3	64.8	26.8	19.6	23.2	32.3	7.1	7.3	
2	62.5	62.5	55.5	55.5	50.0	44.8	46.6	37.5	60.7	62.5	40.9	37.5	41.1	40.9	53.4	62.5	
3	62.5	62 5	0.9	59.0	48.4	53.9	59.1	55.3	53.9	62.5	52.1	48.4	37.5	39.3	69.1	67.6	
4	60.7	65.9	34.1	25.0	21.6	25.2	19.7	23.4	39.4	28.5	28.4	23.2	23.4	25.0	39.1	39.1	
5	35.3	37.3	12.5	12.5	12.8	14.3	14.5	10.4	34.3	23.4	23.4	12.5	14.5	21.6	19.6	32.1	
6	71.6	78.7	25.0	8.9	37.6	14.3	12.5	12.5	42.8	23.2	35.8	35.7	14.3	12.5	46.4	85.9	
7	95.0	96.8	77.0	60.6	26.4	30.0	21.0	26.4	88.0	79.1	87.7	86.1	31.8	24.6	93.2	93.3	
8	53.2	71.4	64.8	56.9	28.7	26.8	41.4	63.0	80.3	85.7	73.2	57.3	75.9	48.4	40.7	23.2	
MEAN	66.2		40.7		33.1		32.6		55.8		43.0		32.0		48.7		44.0

TABLE 23

Analysis of variance for the percentage of vote from the SDS ballot

Source	d.f.	Mean squares	F-value
T	2	6491.37	58.61**
FC	7	2441.67	22.04**
S	7	4457.24	40.24**
T x FC	14	185.35	1.67
T x S	14	299.29	2.70**
FC x S	49	317.38	2.87**
ERROR	98	110.76	
Total	191		

**$\alpha \leqslant 1\%$

*$\alpha \leqslant 5\%$

TABLE 24

Duncan's multiple range test on mean percentage of votes for replications from the SDS ballot.*

Replication	1	2
Vote %	34.2	34.4
	AAAAAAAAAAAA	

* Means with the same letter are not significantly different.

TABLE 25

Duncan's multiple range test on percentage of votes for the still air condition from the SDS ballot.*

"still air"	End	Begining
vote %	45.5	50.5
	AAAAAAAAAAAAAAAA	

* Means with the same letter are not significantly different.

TABLE 26

Duncan's multiple range test on percentage of votes for temperatures and fan conditions from the SDS ballot.*

Temperature(C)	25.6	27.8	30
vote %	23.9	35.0	44.0
	C	B	A

	Air velocity, m/s							
	Fix.	Osc.	Osc.	Fix.	Osc.	Fix.	Start	End
Fan condition	1.2	.7	.5	.8	.3	.4	.2	.2
Vote %	24.4	24.6	26.6	30.7	30.9	41.2	45.5	50.5
	AAAA	AAAA	AAAA	AAAA	AAAA		BBBB	BBBB
						CCCC	CCCC	

* Means with the same letter are not significantly different.

TABLE 27

Duncan's multiple range test for percentage of votes for subjects from the SDS ballot.*

Subject	5	6	4	1	2	7	8	3
Vote %	16.2	22.4	23.5	25.9	42.8	45.2	47.8	50.8
	D	C	C	C		A	A	A
					B	B	B	

---

* Means with the same letter are not significantly different.

Figures 27, 28, and 29 show the different fan conditions at different temperatures. These figures also show that subjects feel cooler with higher air velocities. Figure 30 shows an overall look at the difference between the oscillating fan and the fixed fan.

Figure 31 shows the different fan conditions at different temperatures.

An analysis of variance (Tables 28 and 29) was performed on the percentage of votes for the oscillating fan and the percentage of votes for the fixed fan. Temperature and air velocity was significant for both the fixed and oscillating fan. The interaction between the air velocity and temperatures was not significant for either fan.

Table 30 shows the Duncan's multiple range test for the mean percentage vote of the temperatures and air velocities for the oscillating fan. Temperatures were significantly different. Air velocities of .5 m/s and .7 m/s are not significant, while both velocities are significantly different from the air velocity of .3 m/s. Table 31 shows the Duncan's multiple range test for the mean percentage vote of the temperatures and air velocities for the fixed fan. Temperatures and air velocities were significantly different.

Figures 32 and 33 show the air velocities for the oscillating and fixed fan at different temperatures.

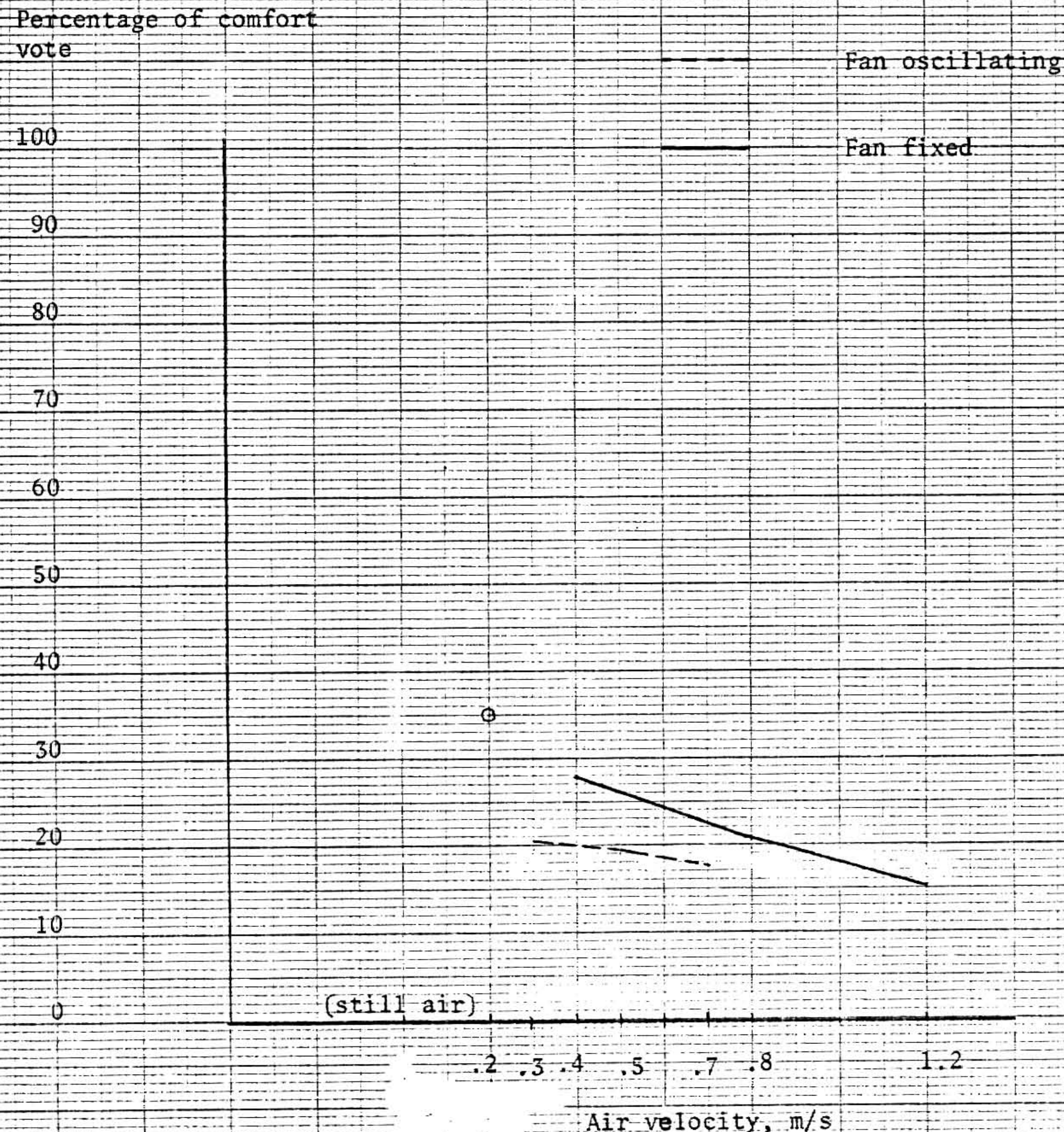

Figure 27. Percentage of votes for air velocity from an oscillating and fixed fan at a temperature of 25.6 C from the SDS ballot.

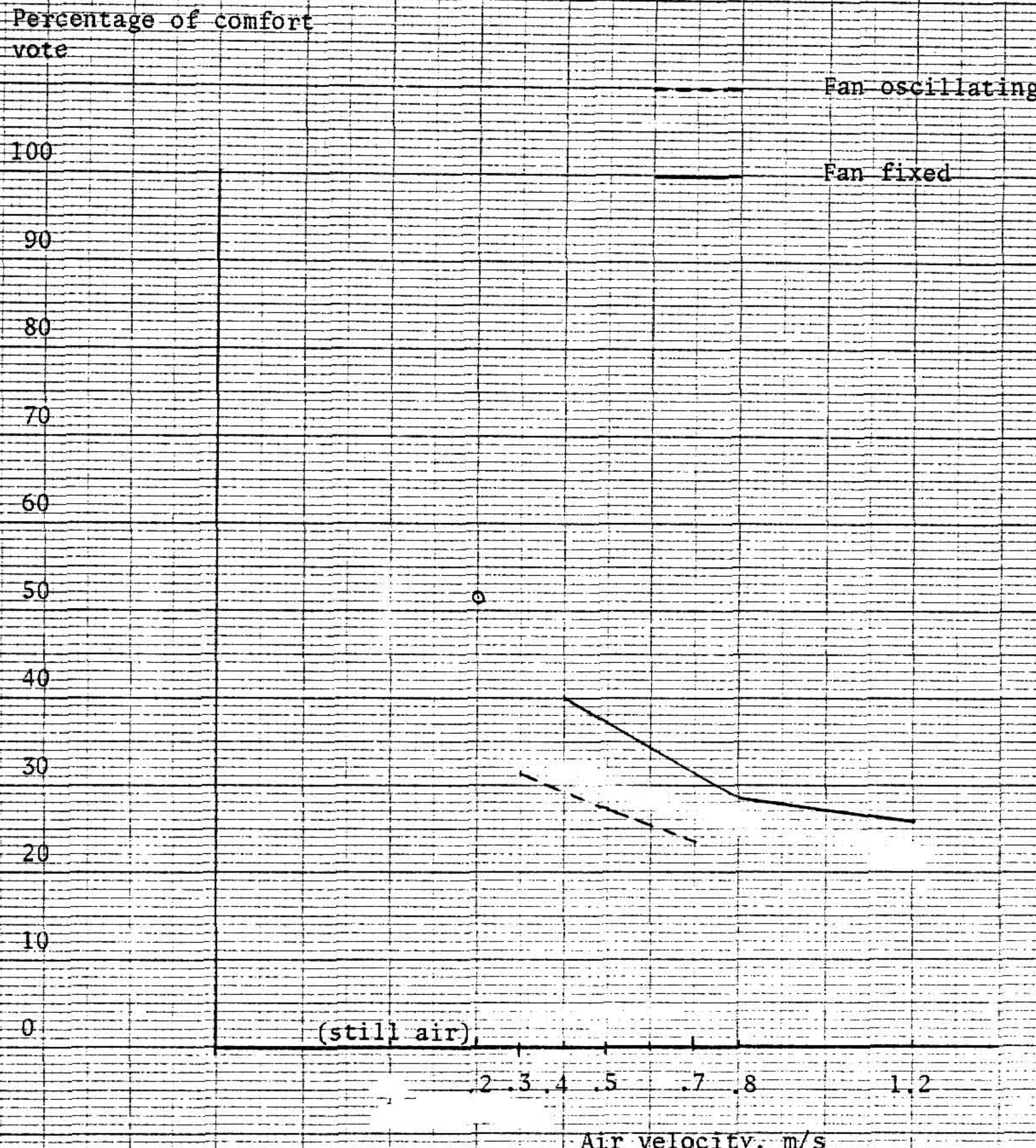

Figure 28. Percentage of votes for air velocity of an oscillating and fixed fan at a temperature of 27.8 C from the SDS ballot.

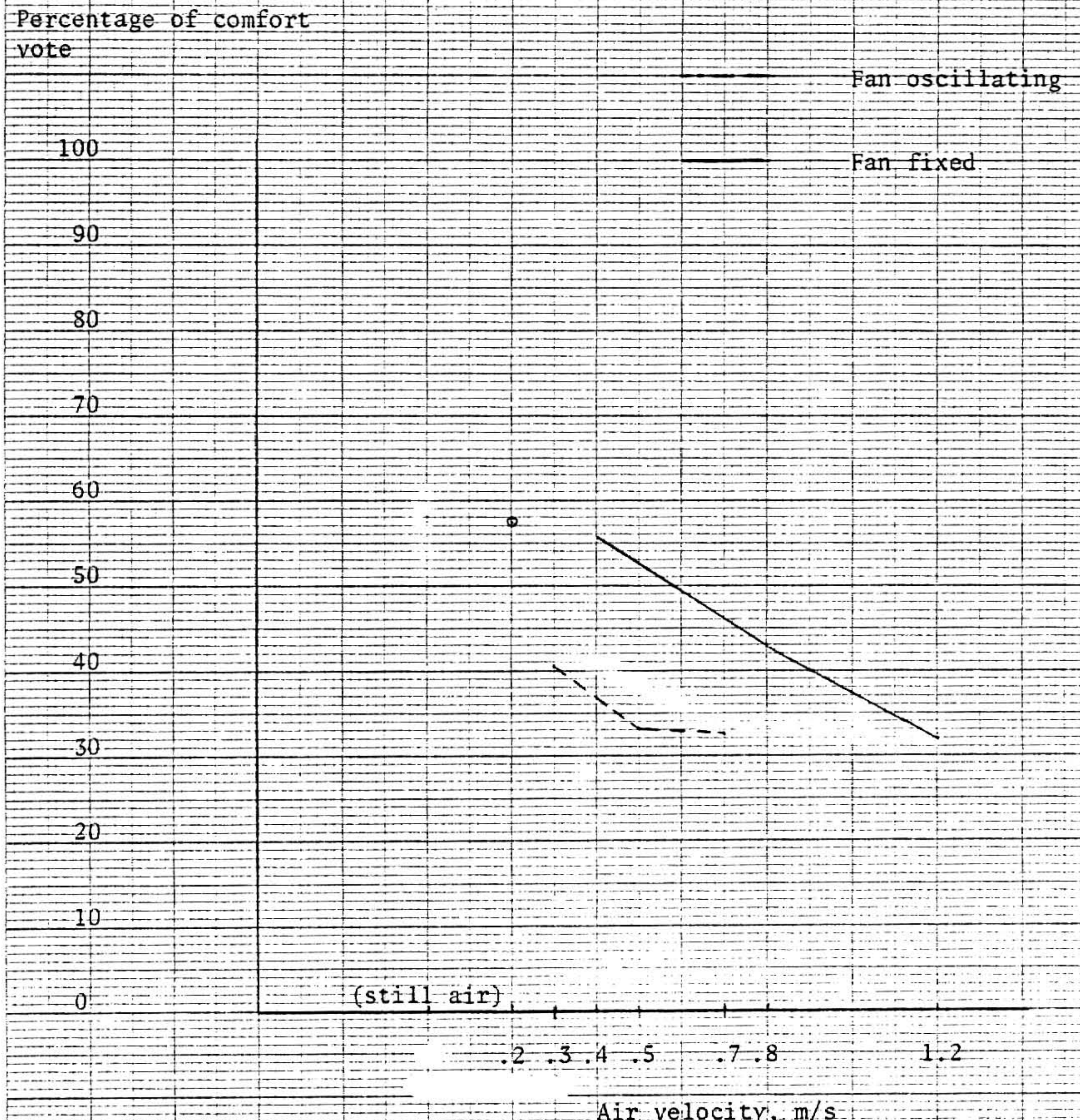

Figure 29. Percentage of votes for air velocity from an oscillating and fixed fan at a temperature of 30 C from the SDS ballot.

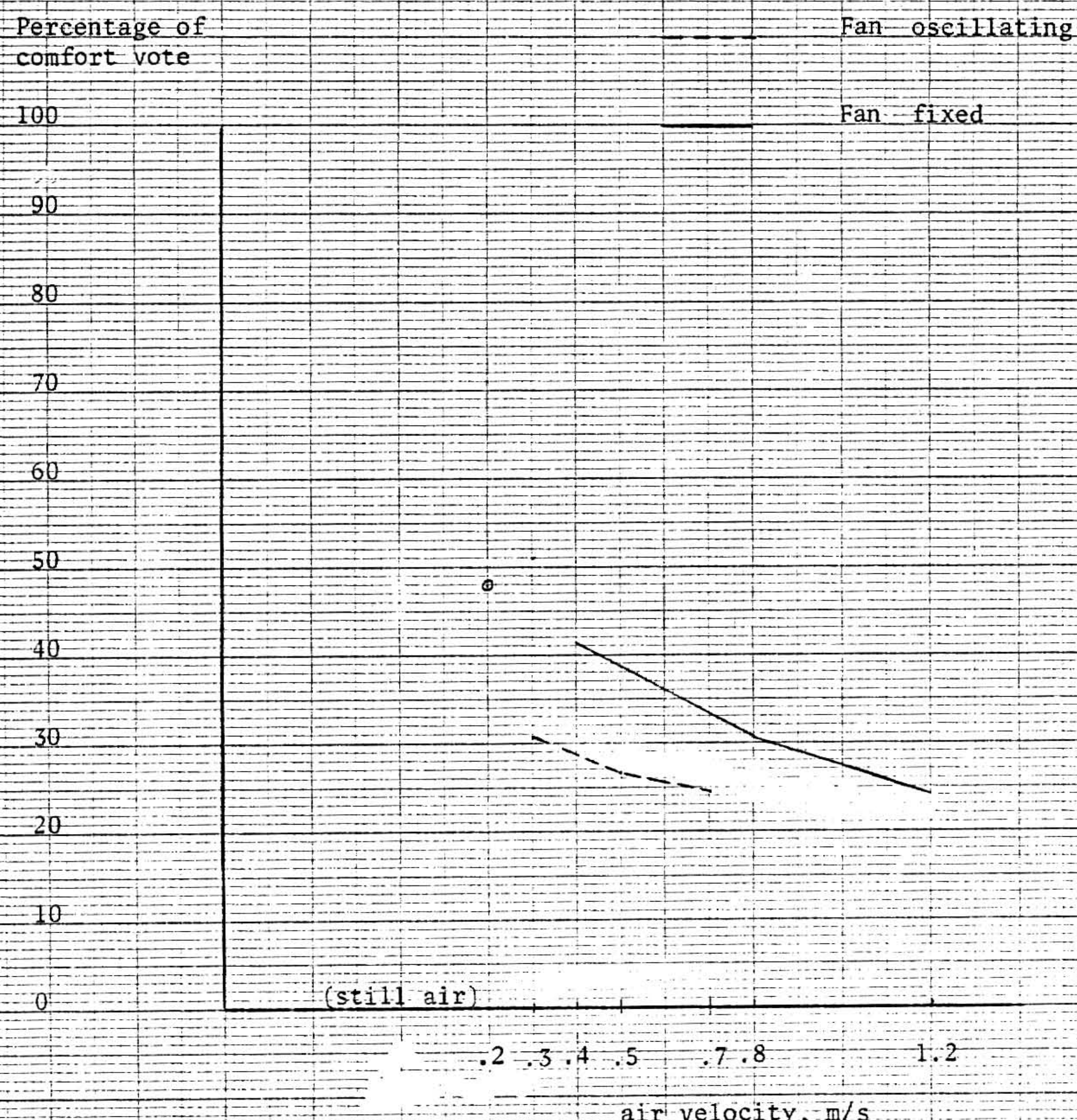

Figure 30. Overall percentage of votes for the oscillating and fixed fan from the SDS ballot.

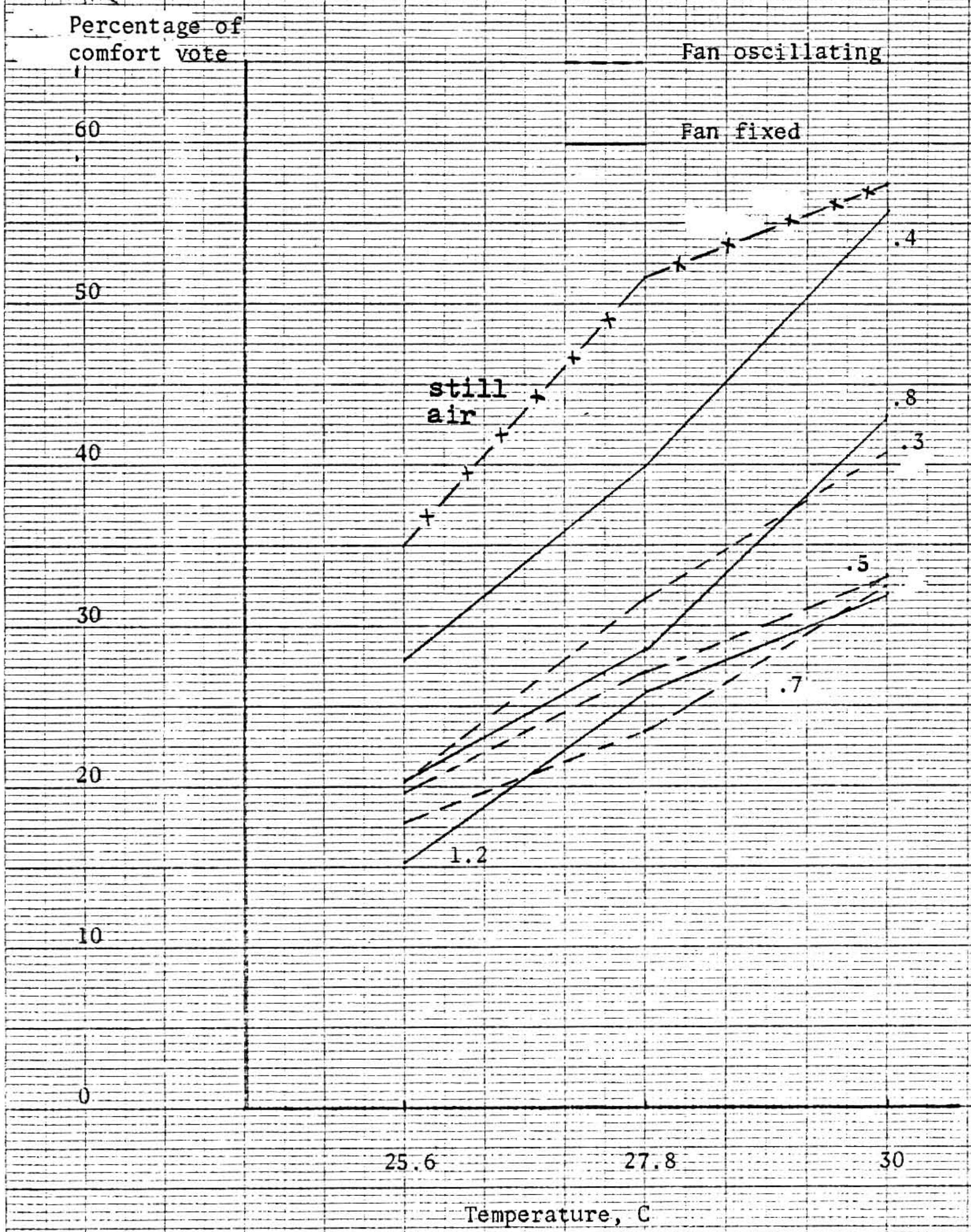

Figure 31. Percentage of vote for air velocities at different temperatures by fan conditions from the SDS ballot.

TABLE 28

Analysis of variance on the percentage of votes for the oscillating fan from the SDS ballot.

Source	d.f.	Mean square	F-value
T	2	1582.97	37.66**
AV	2	243.99	5.81**
S	7	1813.75	43.15**
T x AV	4	33.81	.80
T x S	14	63.34	1.51
AV x S	14	197.31	4.69**
ERROR	28	42.03	
Total	71		

** $\alpha \leqslant 1\%$

* $\alpha \leqslant 5\%$

TABLE 29

Analysis of variance for percentage of votes for the fixed fan from the SDS ballot.

Source	d.f.	Mean square	F-value
T	2	3012.32	39.01**
AV	2	1737.29	22.50**
S	7	1878.30	24.33**
T x AV	14	83.78	1.09
T x S	14	210.11	2.72*
AV x S	14	135.70	1.76
ERROR	28	77.21	
Total	71		

**$\alpha \leqslant$ 1%

*$\alpha \leqslant$ 5%

TABLE 30

Duncan's multiple range test for percentage of votes for the oscillating fan by temperature and air velocity from the SDS ballot.*

Temperature (C)	25.6	27.8	30
Vote %	19.2	27.4	35.5
	C	B	A
Air velocity (m/s)	.7	.5	.3
Vote %	24.6	26.6	30.9
	BBBBBBBBBBBBB		A

* Means with the same letter are not significantly different.

TABLE 31

Duncan's multiple range test for percentage of votes for the fixed fan by temperature and air velocity from the SDS ballot.*

Temperature (C)	25.6	27.8	30
Vote %	21.2	31.5	43.6
	C	B	A
Air velocity (m/s)	1.2	.8	.4
Vote %	24.4	30.7	41.2
	C	B	A

* Means with the same letter are not significantly different.

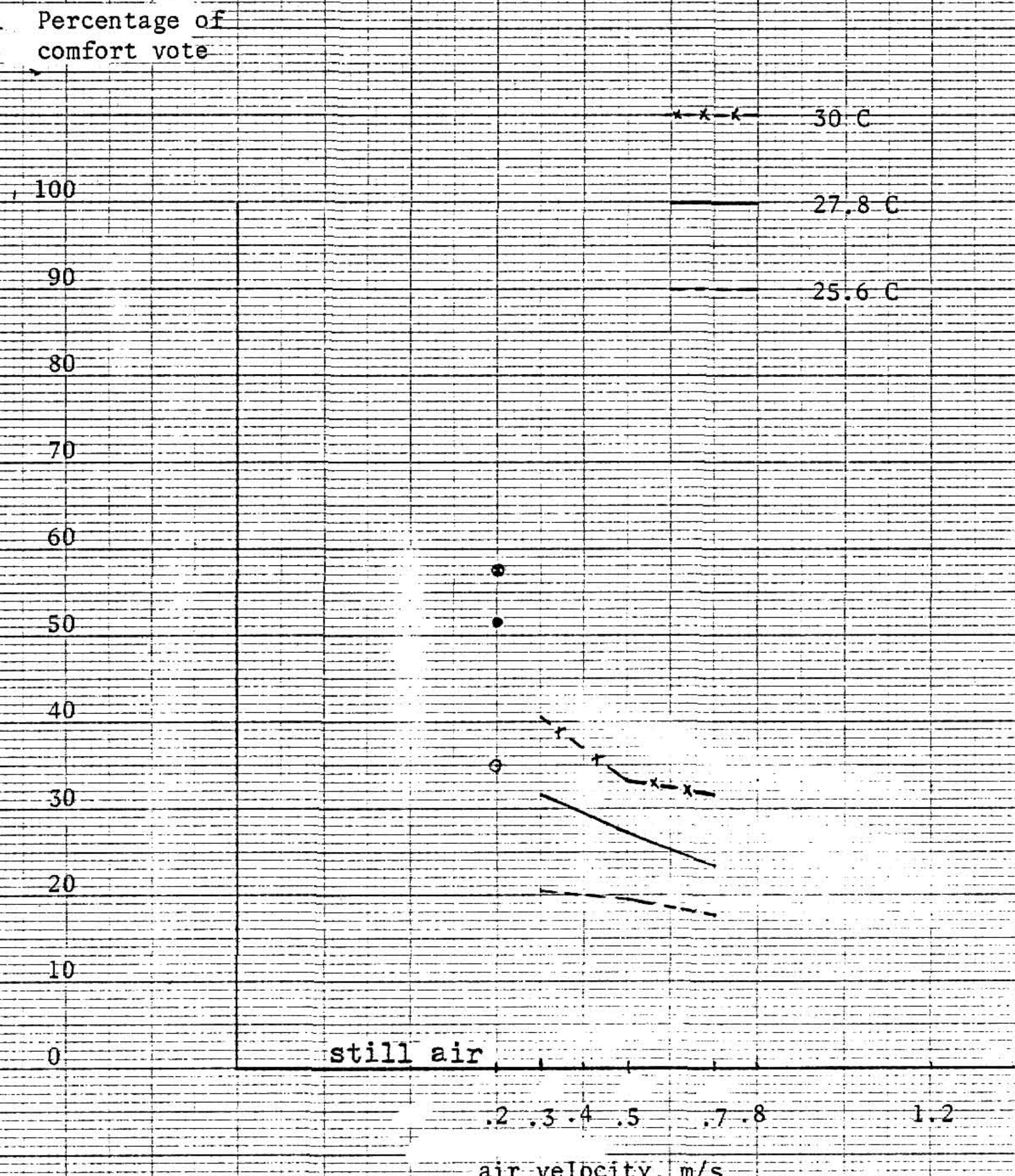

Figure 32. Air velocities of the oscillating fan at different temperatures from the SDS ballot.

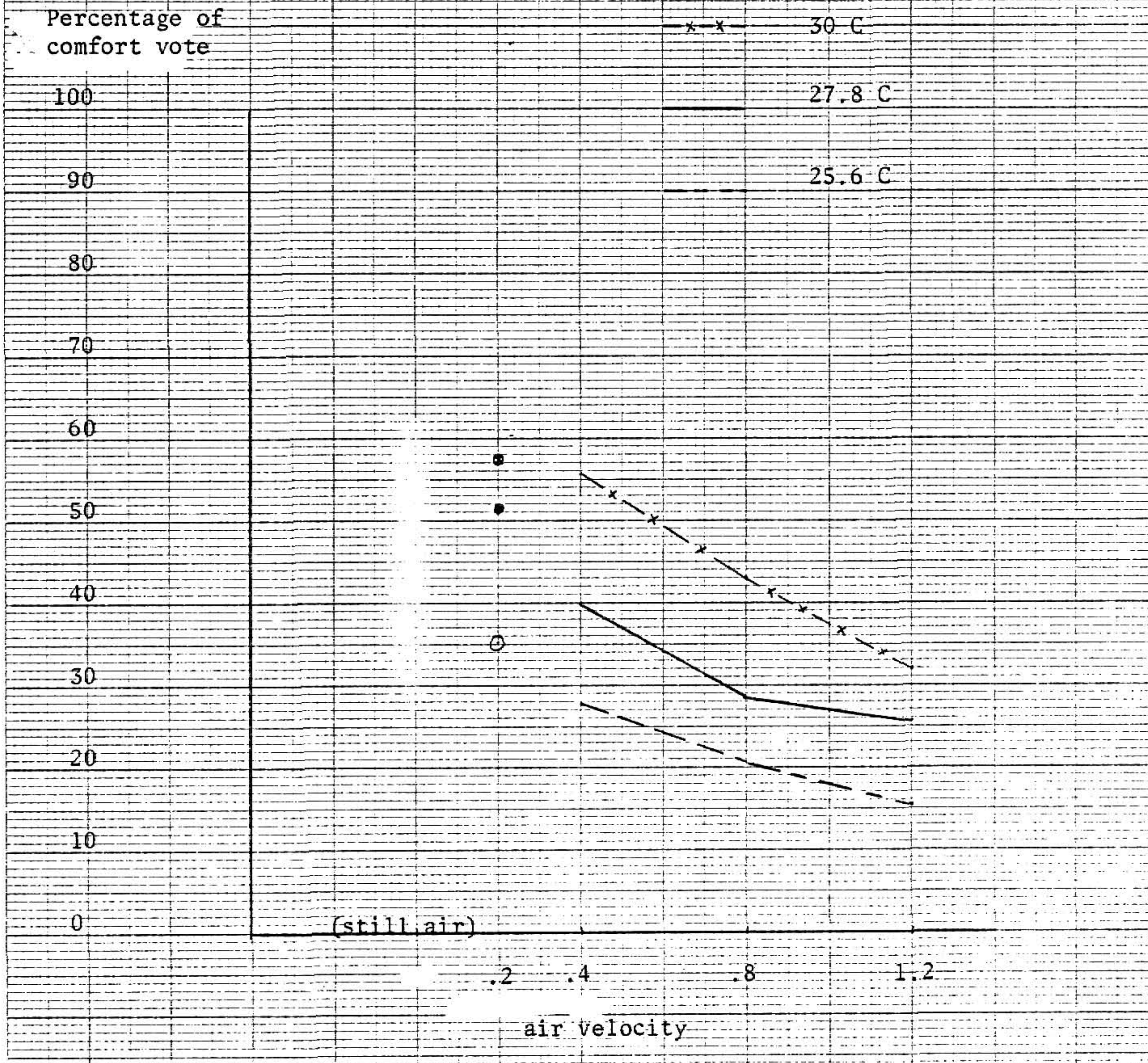

Figure 33. Air velocities of the fixed fan at different temperatures from the SDS ballot.

Noise: In a pilot experiment, noise ballots were used to determine the effect of noise. Results indicated that noise had no effect. Figure 34 shows the mean vote for the noise at two experimental conditions (fan oscillating at a velocity of .8 m/s and a "still air" condition). The mean vote for the "still air" condition was higher than that of the fan oscillating at a velocity of .8 m/s. The humidifier noise was higher than that produced by the oscillating fan.

Prediction of votes: A multiple regression analysis was performed for the two fan conditions (oscillating and fixed); see Table 32. These equations apply only for the experimental conditions that have been discused in this study. The predicted votes from the equations are the comfort votes from the thermal sensation ballot. Table 32 shows that the correlation cofficient for the fixed fan is higher than that of the oscillating fan.

From the equation, for every increase in the air velocity by 1 m/s the temperature can be increased by 5.3 C for the fixed fan. For the oscillating fan, for every increase in the air velocity by 1 m/s the temperature can be increased by 8.8 C.

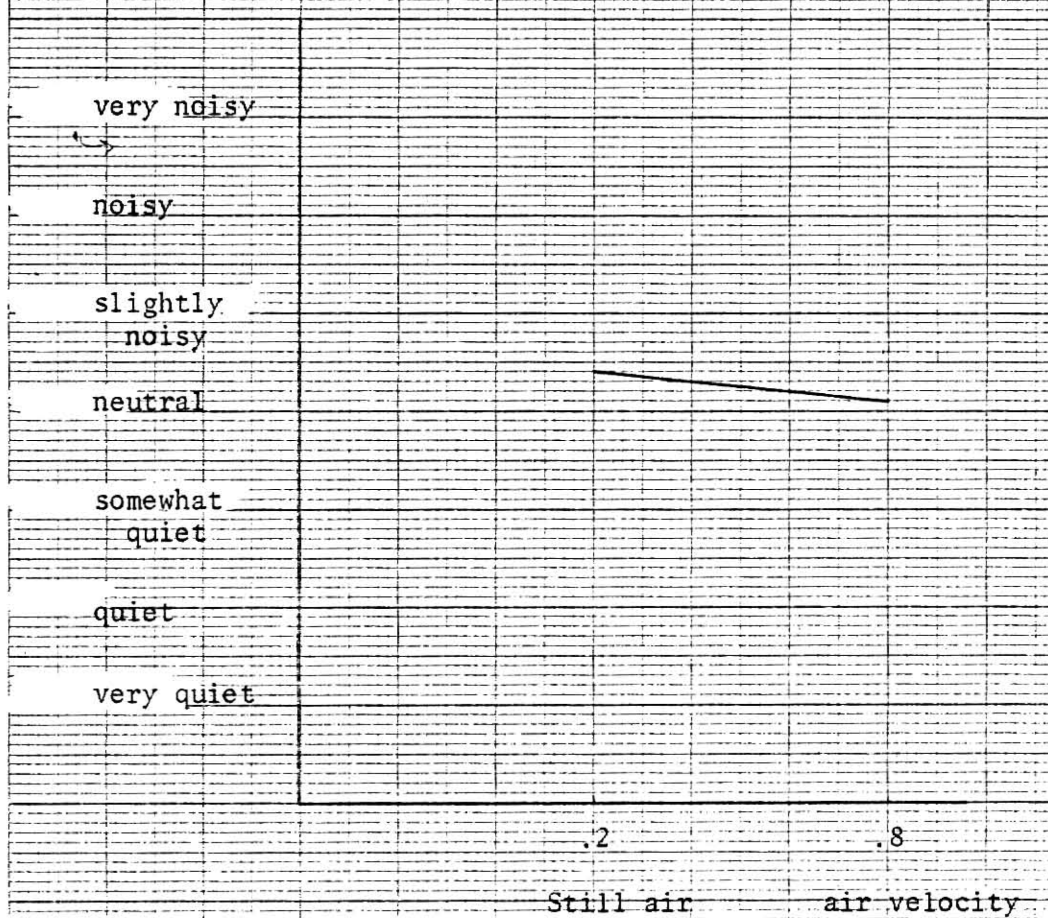

Figure 34. The mean votes from the noise ballot by fan condition.

TABLE 32

Multiple regression equations for predicting the comfort vote for the oscillating and fixed fan.

Fan condition	Regression equation*
Oscillating	$V = -.457 + .225(T) - 2.193(AV)$
	$R^2 = .331$
Fixed	$V = -1.113 + .257(T) - 1.367(AV)$
	$R^2 = .439$

* still air was assumed to equal .2 m/s.

DISCUSSION

Air velocity: At higher velocities subjects voted cooler. This can be seen in Figures 18, 19 and 20 for the thermal sensation ballot and Figures 27, 28, and 29 for the semantic-differential scale ballot and Table 32.

For the "still air" condition, mean votes ranged between slightly warm and neutral. The range of the mean votes may be an indication that higher temperatures may be needed to be investigated in future experiments. From the thermal sensation ballot, the mean vote (4.9) for the "still air" condition at the beginning of the experiment at a temperature of 25.6 C is the same as the mean vote (4.9) for the air velocity of .7 m/s from an oscillating fan at a temperature of 30 C. There was no difference also between the mean vote (5.4) of the "still air" condition at the end of the experiment at a temperature of 25.6 C and the fan fixed at a velocity of .8 m/s at a temperature of 30 C. For the semantic-differential scale ballot the means of the conditions mentioned above are not significantly different using the least square means test, as for the first condition ("still air" at 25.6 C vs fan oscillating at 30 C with a velocity of .7 m/s), the probability of being significant is $p \leq .60$. The probability of the second comparison is $p \leq .56$.

Figures 25 and 31 show the mean vote from the thermal sensation ballot and the mean percentage vote from the semantic-differential scale ballot of the air velocities of 1.2 and .7 m/s. It shows that the means are below that necessary for thermal comfort. This is the case also for the velocities of .8 and .5 m/s for the fan conditions, see Figures 24 and 31. In general, the air velocities of 1.2 and .7 m/s were felt cooler than the air velocities of .8 and .5 m/s and the air velocities of .4 and .3 m/s for both fan conditions. See Tables 33 and 34.

With the fan fixed, the velocity of .4 m/s was felt equal to the "still air" condition. This is true for all temperatures (25.6, 27.8 and 30 C). This can be seen clearly in Figures 26 and 33. This could be due to the volume of the air produced from the fan, which is relativily low because of the size of the fan (nine inch) that was used for the experiment. Another reason could be that the air velocity was determind by moving the fan forward or backward, so in order to reach a velocity of .4 m/s for the fixed fan, the fan should be approximately 4.4 meters (14.5 feet) from the subject. The distance of the fan could have had a psychological effect. This could be investigated further by subjects responses when they were asked which fan condition they preferred. Most of the subjects replied
ferred the fan when it was closer to them.

TABLE 33

Mean votes for the interaction between the fan condition and the temperature from the thermal sensation ballot.

Temperature (C)	Fan condition	Air velocity (m/s)	Mean vote
25.6	still air	.2 start	4.9
	still air	.2 end	5.4
	oscillating	.3	4.3
		.5	3.9
		.7	3.9
	fixed	.4	4.8
		.8	4.3
		1.2	4.0
27.8	still air	.2 start	5.9
	still air	.2 end	6.0
	oscillating	.3	4.8
		.5	4.9
		.7	4.6
	fixed	.4	4.7
		.8	4.8
		1.2	4.4
30	still air	.2 start	6.8
	still air	.2 end	5.8
	oscillating	.3	5.1
		.5	4.9
		.7	4.9
	fixed	.4	6.1
		.8	5.4
		1.2	5.0

TABLE 34

Mean percentage of votes for the interaction between the fan condition and the temperature from the SDS ballot.

Temperature (C)	Fan condition	Air velocity (m/s)	Mean percentage of vote
25.6	still air	.2 start	29.9
	still air	.2 end	40.0
	oscillating	.3	20.3
		.5	19.6
		.7	17.8
	fixed	.4	27.9
		.8	20.4
		1.2	15.3
27.8	still air	.2 start	55.4
	still air	.2 end	47.9
	oscillating	.3	31.6
		.5	27.1
		.7	23.4
	fixed	.4	40.0
		.8	28.6
		1.2	25.9
30	still air	.2 start	66.2
	still air	.2 end	48.7
	oscillating	.3	40.7
		.5	33.1
		.7	32.6
	fixed	.4	55.8
		.8	43.0
		1.2	32.0

Oscillating and fixed fan: Table 25 shows the preferred fan condition at different temperatures according to the mean vote from the thermal sensation ballot and the mean percentage vote from the semantic-differential scale ballot.

At low velocities, the oscillating fan was preferred over the fixed fan for all temperatures. At medium velocities the oscillating fan was preferred over the fixed fan at a low temperature of 25.6 C and also at a high temperature of 30 C. At the temperature of 27.8 C the mean vote from the thermal sensation ballot shows that the oscillating fan was preferred while the mean percentage vote from the semantic-differential scale ballot shows that the fixed fan was preferred. But the difference between the fan conditions at the temperature 27.8 C is relativily low for both means, see Figures 24 and 31.

At the air velocities of 1.2 and .7 m/s it is very difficult to indicate the preferred fan condition. The difference between both conditions by the mean vote from the thermal sensation ballot and the mean percentage vote from the semantic-differential scale ballot is very small as can be seen in Figures 25 and 31. This difference also can be seen in Duncan's multiple range test, as Table 14 shows that the oscillating fan was preferred, while Table 26

TABLE 35

Preferred fan condition by air velocity and temperature.

Temperature (C)	Air velocity	Preferred condition ThS	SDS
25.6	L	FO	FO
	M	FO	FO
	H	FO	FF
27.8	L	FO	FO
	M	FF	FO
	H	FF	FO
30	L	FO	FO
	M	FO	FO
	H	FO	FF

FO - Fan Oscillating.

FF - Fan Fixed.

L - Low (.4 m/s fixed and .3 m/s oscillating).

M - Mid (.8 m/s fixed and .5 m/s oscillating).

H - High (1.2 m/s fixed and .7 m/s oscillating).

shows that the fixed fan was preferred. It was indicated earlier in this study that one of the properties of the oscillating fan is that the subject is exposed to an air flow (at a certain air velocity) which will be higher or lower depending on the fan cycle. See Figures 14, 15 and 16. So the difference between the mean air velocity at each second of the cycle is greater at higher air velocities than the difference between the mean air velocities at every second of the cycle with lower velocities. This could be the reason why the oscillating fan is preferred at lower air velocities (.3 and .5 m/s) and not at higher air velocities (.7 m/s). Further investigation may be needed to determine this.

For an overall look, Figures 21 and 30 shows that at lower air velocities the oscillating fan was preferred while at higher air velocities both fan conditions seem to be the same.

Figures 21, 23, 24, and 25 show that for every increase in the velocity by 1 m/s the temperature should be increased by 2.2 C for the oscillating fan. For the fixed fan the figures show that for every increase in the air velocity by 1 m/s the temperature should be increased by 5.5 C.

From above it seems that the air velocity from the fixed fan is 2.5 times more important than the air velocity from the oscillating fan in determining thermal sensation. This is in contrast with Nevins (1975) values that says that, for every 1 m/s increase between .6 and 1.0 m/s the temperature should be increased by 1.5 C. This increase in temperature is greater than that needed for the oscillating fan and four times less than that of the fixed fan. The values of the trade off for the oscillating fan is six times less than that obtained from the regression equation (8.8 C for every 1 m/s increase), while the fixed fan values are similar (5.3 C for every 1 m/s increase). Further investigation may be needed on this subject.

The fluctuation of air flow may have had an influence on creating thermal comfort. Results indicated that this influence was in the positive direction.

Temperature: Independent from the fan condition, or air velocity, mean vote and mean percentage vote of the different temperatures seem to lie in the thermal comfort zone. The one exception is the mean vote and mean percentage vote for the air velocity of .4 m/s at different temperatures for the fixed fan.

Thermal sensation and the semantic differential scale ballots: Results from both ballots were somewhat identical to each other (with a few exceptions). This may give a good indication of how reliable the experiment was.

CONCLUSIONS

1- There was no difficulty in creating thermal comfort independent from the temperature or the air velocity.

2- Subjects felt cooler with higher air velocities, independent from the temperature or fan condition.

3- An air velocity of .4 m/s from the fixed fan was felt equal to the "still air" condition independent of the temperature.

4- Oscillating fans were preferred over fixed fans at lower air velocities, while both fan conditions had the same effect with higher air velocities.

5- The low volume of air produced from the fan may have had its positive effects on comfort for high velocities and a negative effect on comfort with low air velocities.

6- The fluctuation (turbulence) of the fan while it was fixed or oscillating could have had a positive effect on creating thermal comfort.

7- The air velocity from the fixed fan was three times more important than the air velocity from the oscillating fan when determining thermal sensation.

ACKNOWLEDGMENT

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REFERENCES

1. ASHRAE, Handbook of Fundamentals, New York. American Society of Heating, Refrigerating, and Air Conditiong Engineers, 1977.

2. Berdan, C., Gavrilescv, N., Vaida, I., Pafnote, M., and Tarpa, G., Researches into the efficiency of air shower in hot work, Egonomics and Physical Environmental Factors, International Labor Office, Geneva 1970, 379-383.

3. Cena, K. and Clark J. A., Bioengineering Thermal Physiology and Comfort. Elsevier Scientific Publishing Company, 1981

4. Consumer Reports, Buying Guide Issue 1980, December 1979, 44, 135-142, No. 12.

5. Fanger, P. O., Thermal Comfort, McGraw-Hill Book Company, 1970.

6. Fanger, P. O., Ostergaard, J., Olesen, S., Lund Madsen, Th., The effect on man's comfort of a uniform air flow from different directions, ASHRAE Transactions, 1974, 80, Part 2, No. 2312

7. Fanger, P. O., Comfort at workplaces by spot cooling, submitted to the XIV International Congress of Refrigeration, Moscow, Sept. 1975.

8. Fanger, P. O. and Valbjorn, O., The effect of air movement of thermal comfort and sensation, Indoor Climate, Danish Building Research Institute, 1979, 541-560.

9. Ingram, D. L., and Mount, L. E., Man and Animals in Hot Environments, Springer-Verlag, New York Inc., 1975. 158-159.

10. Konz, S. A., Work Design, Grid Publishing, Inc. Columbus, Ohio, 1979.

11. McIntyre, D. A., Preferred air speeds for comfort in warm conditions, ASHRAE Transactions, 1978, 255-277, Part 2, No. 2507.

12. Nevins, R. G., Energy conservation strategies and human comfort. ASHRAE Journal, April 1975, 33-37.

13. Olesen, S., Fanger, P. O., Bassing, J. J., Physiological comfort conditions at sixteen combinations of activity, clothing, air velocity and ambient temperature, ASHRAE Transactions, 1972, 78, Part II, No. 2254.

14. Rohles, F. H., Wind as an aversive stimulus, Journal of the Experimental Analysis of Behavior, 1965, 8, 203-205.

15. Rohles, F. H., A psychologist looks at air movement, ASHRAE Journal, July 1965, 48-49.

16. Rohles, F. H., Nevins, R. G., and Springer, W. E., Thermal characteristics of body temperature during high thermal stress, Aerospace Medicine, March, 1967, 38, 286-290.

17. Rohles, F. H., Thermal sensation of sedentary man in moderate temperatures, Human Factors, 1971, 13, 6, 553-560. Reprint No. 34.

18. Rohles, F. H., and Nevins, R. G., The nature of thermal comfort for sedentary man, ASHRAE Transactions, 1971, 77, Part I.

19. Rohles, F. H., Woods, J. E., and Nevins, R. G., The effects of air movement and temperature on the thermal sensations of sedentary man, ASHRAE Transactions, 1974, 9-28, No. 2298.

20. Rohles, F. H., Temperature or temperament: A Psychologist looks at thermal comfort, ASHRAE Transactions, 1980, 86, Part I, No. 5.

21. Thermal Environment Conditions for Human Occupancy, ASHRAE Standard, Draft Revision, April, 1980.

APPENDIX A

SYMBOLS

ThS	=	Thermal sensation ballot
SDS	=	Semantic differential scale ballot
T	=	Temperature, C
F	=	Fan condition
AV	=	air velocity, m/s
S	=	subjects
V	=	vote

APPENDIX B

INSTRUCTIONS

This experiment is designed to measure your comfort in three different temperatures of 78, 82, and 86 F (25.6, 27.8, and 30 C).

You are required to perform a pegboard assembly task (you are required to pick up doubles from a bin one at a time using your preferred hand and place them on a pegboard with the white side up and in the two middle columns. You will then disassemble the board and repeat the entire process) [See sample on Table] at three different times on three different days, and in seven conditions:

1. Performing the task in still air (no fan will be in use).

2,3,4. Performing the task while a fan is oscillating, at three air velocities.

5,6,7. Performing the task while a fan is in a fixed position, at three different velocities.

Before entering the experimental chamber, you are required to change your clothes and wear a shirt (long sleeves, cotton twill), trousers (cotton), jockey shorts, shoes and socks (cotton). You provide the underwear, socks, and shoes; we provide the shirt and trousers. After entering the experimental chamber you are going to be given three kinds of ballots. These are the ballots that you will be handed every ten minutes of the experiment to mark (these will be explained to you before you begin with the experiment) (See attachment).

There will be approximately 3 hours of experimental time for each day, for a total of 9 hours in three days. You will be paid, at the end of the experiment, a sum of $45.

There will be no risk in this experiment. However you are free to stop at any time although it is recommended that you continue to the end so that I can get all the data needed and you need not forfeit your pay. Feel free to ask any questions at any time, now or later. If you agree to participate, you are required to complete a subject data form.

I hereby agree to participate in the experiment: "Using Fans to Improve Comfort at 78, 82, and 86 F."

____________________________ ________________

(Signature) (Date)

APPENDIX C

Subject data form

Name: ______________________________________
(First) (Last)

Phone: ______________________________________

Birth Date: __________________________________

Weight: ______________________________________

Height: ______________________________________

Sex M F

Do not write below this line

Subjects Code ________

Subjects Attendance:

	First Day	Second Day
Day	M T W T F S S	M T W T F S S
Date	________	________
Time Beginning	________	________
Time Ending	________	________

APPENDIX D

Thermal Sensation Ballot

Circle the number that best describes how you feel.

9	very hot
8	hot
7	warm
6	slightly warm
5	neutral
4	slightly cool
3	cool
2	cold
1	very cold

APPENDIX E

Semantic Differential Scale Ballot

Place an (X) between each pair at the location that best describes how you feel.

Comfortable:	__:__:__:__:__:__:__:__:__:	Uncomfortable
Bad Temperature :	__:__:__:__:__:__:__:__:__:	Good Temperature
Pleasant :	__:__:__:__:__:__:__:__:__:	Unpleasant
Good Ventilation:	__:__:__:__:__:__:__:__:__:	Poor Ventilation
Unacceptable :	__:__:__:__:__:__:__:__:__:	Acceptable
Uncomfortable Temperature :	__:__:__:__:__:__:__:__:__:	Comfortable Temperature
Satisfied :	__:__:__:__:__:__:__:__:__:	Dissatisfied

USING OSCILLATING FANS
TO IMPROVE COMFORT

by

SUDAD S. AL-WAHAB

B.Sc., Statistics, Baghdad University, 1976

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Industrial Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1981

ABSTRACT

Using oscillating fans to improve comfort.

SUDAD STANLY AL-WAHAB, Kansas State University, Manhattan, KS 66506

Eight subjects sat in an experimental chamber and performed a pegboard task three different times at three different temperatures (25.6, 27.8, and 30 C). In each temperature there were seven conditions (1- Performing the task in still air, no fan in use; 2,3,4- Performing the task while the fan was in a fixed position at three air velocities; 5,6,7- Performing the task while the fan was oscillating at three air velocities). Air velocities were at .4, .8, and 1.2 m/s.

Each subject was exposed to each temperature and fan condition for 20 minutes. Two types of ballots measured the subjects thermal sensation.

Results indicated that temperatures and fan conditions were significantly different. The interactions between fan conditions and temperatures were not significant.

Subjects felt cooler with higher air velocities independent of the fan condition or temperature.

At lower temperatures the oscillating fan was perferred over the fixed fan, while at higher temperatures both fan conditions had the same effect. For every increase in air velocity by 1 m/s the temperature can be increased by 2.2 C for the oscillating fan and by 5.5 C for the fixed fan.